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FUEL TESTS WITH HOUSE-HEATING BOILERS

BY

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UNIVERSITY OF ILLINOIS
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ENGINEERING EXPERIMENT STATION

BULLETIN NO. 31 FEBRUARY 1909

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CONTENTS

II. FUEL TESTS WITH HOUSE-HEATING BOILERS MADE BY THE UNITED STATES GEOLOGICAL SURVEY
(58 tests: 47 with briquetted fuel; 11 with raw fuel)

III. FUEL TESTS WITH HOUSE-HEATING BOILERS MADE BY THE ENGINEERING EXPERIMENT STATION
(24 tests with briquetted fuel)

General Introduction

This bulletin describes one hundred thirty fuel tests with house-heating boilers. For convenience, it has been divided into three parts.

Part I describes 48 tests made by the Engineering Experiment Station of the University of Illinois, when burning the various kinds of fuel commonly used in house-heating work in the state of Illinois.

Part II relates to 58 tests made under the direction of the United States Geological Survey at St. Louis, Missouri. Of these tests, 47 were upon briquetted fuel, and 11 upon raw coal.

Part III describes 24 tests made by the Engineering Experiment Station of the University of Illinois, using briquetted fuel.

All these tests were conducted under conditions which differed considerably, and by methods differing more or less in detail. The tests made by the Engineering Experiment Station at the University of Illinois extend over a considerable length of time and have been carried on by regular members of the fuel test division, occasional changes in the personnel having been required. The observations on the tests made at St. Louis were all made by one observer. For these reasons, therefore, the results are hardly comparable, except in a more or less general way, and little attempt has been made to make such comparisons.

The descriptive matter and discussion included in each part apply to its own series of tests, unless otherwise stated. Most of this descriptive matter and discussion has been incorporated in connection with the tests of Part I. Part II and Part III are for the most part a compilation of data and results of the tests considered. The tests made at St. Louis under the supervision of the United States Geological Survey are reported and discussed in Bulletin 366 issued by that department. The Engineering Experiment Station is under obligation to the United States Geological Survey for the information concerning the St. Louis tests here published.

I. Fuel Tests with House-heating Boilers made by the Engineering Experiment Station
(48 tests with representative fuels)

1. *Introduction*

The purpose of these tests was in general two-fold. First, to obtain the information usually obtained from boiler trials when operating upon house-heating boilers with various types of fuel commonly used for domestic purposes, in order that comparison might readily be made; second, to obtain information that might assist in developing satisfactory methods for conducting house-heating boiler trials whether the object of the test be to test the fuel, the equipment, or the two combined.

Some of the more important deductions drawn have been summarized in the paragraphs immediately following. The data and discussion relative to these deductions will be found in subsequent portions of the bulletin. The conclusions regarding methods for conducting house-heating boiler trials, having been drawn from one series of tests during which most of the important conditions were maintained constant, they can be considered as of only a preliminary nature. Further tests, under varying conditions, will, it is hoped, furnish further information in this connection. It was deemed advisable to present the information relative to the tests as fuel tests at this time together with such suggestions as could be made in regard to methods for conducting such tests.

2. *Summary of Conclusions*

A. Efficiency and Fuel Cost

(*1*). *The evaporative efficiencies* of house-heating boilers vary greatly with changes in other conditions and extreme care should be used in making comparisons.

(*2*). *The efficiencies* for the tests under consideration varied from 44% to 66%; thus covering about the same range or a somewhat lower range than is found in power boiler work.

(*3*). *A still wider range* of efficiencies will exist under the variable capacity conditions common to average residence heating work.

(*4*). *The range in efficiencies* found was due principally to the different kinds of fuel tested.

(*5*). *Fuels high in fixed carbon content*, such as anthracite and coke, give relatively high efficiencies as compared with fuels low in fixed carbon content.

(*6*). *Present methods of burning and present types of boilers* are particularly well adapted to burning anthracite and other coals high in carbon content.

(*7*). *Coke burning* presents special problems as to methods of burning and construction of equipment.

(*8*). *A high fixed carbon* content as opposed to a high volatile content is desirable in a fuel for domestic purposes.

(*9*). *The low efficiencies* with fuel of high volatile content, such as the Illinois coal, indicate the necessity of improvement as to equipment and methods of burning in order that this fuel may be placed more nearly on an equal footing with other fuels in this respect when employed for house-heating purposes.

(*10*). *Variations in efficiencies*, apparently due to slight changes in fire and other conditions indicate the possibility of obtaining higher efficiencies in many cases by careful attention to details relating to fuel, operation and equipment.

(*11*). *Illinois coal* may be obtained at from $\frac{1}{4}$ to $\frac{1}{2}$ of the cost per ton of anthracite. The cost per British thermal unit will be relatively slightly higher for Illinois coal than when expressed as cost per ton. Roughly, however, 10,000 B. t. u. can be purchased in Illinois coal at from $\frac{1}{4}$ to $\frac{1}{2}$ of the cost in anthracite.

(*12*). *Illinois coal* is considerably cheaper, expressed both as cost per ton and as cost per British thermal unit than Pocahontas coal or coke.

(*13*). *Fixed carbon* can be bought much more cheaply in the form of coke than as anthracite, and at as low or lower a price than it can be purchased in Pocahontas or Illinois coal.

(*14*). *With Illinois coal* as fuel, water can be evaporated in house-heating boilers at about 50% of the fuel cost of anthracite and about 75% of the fuel cost of Pocahontas coal or coke.

(*15*). *The relatively low cost* of Illinois coal especially as compared with the eastern coals will insure its continued use for domestic purposes. The amount of this fuel used for such purposes will probably increase in spite of the disadvantages at present connected with its burning. This condition emphasizes the necessity for improvement in the methods of burning the cheaper fuel.

(*16*). *The low fuel cost* of evaporation for Illinois coal as compared with coke is considerable and will insure the continued use of the raw coal until prices of the two fuels are more nearly equal. Improvement in methods of burning and equipment are needed for burning each of these fuels and such improvements will, doubtless, affect the relative quantity of each which is used.

(*17*). *Improvements* tending toward a reduction of smoke, dirt or other disadvantages connected with the burning of the cheaper coal will, doubtless, also increase the efficiency with which that fuel may be used and make the fuel cost differences still more favorable to the cheaper fuel.

(*18*). *Based upon present prices* of Illinois coal and considering evaporative performance only, anthracite, for instance, is worth only from $3.00 to $4.00 per ton. The additional amount which is paid for it must be considered as expended for advantages possessed by the anthracite, such as cleanliness and ease of fire control, which are not possessed by the other fuel.

B. Cleanliness, Control, Attendance

(*19*). *Anthracite and Pocahontas* coal are particularly well adapted to maintaining uniform pressure and fire conditions over a long period of time with little attention. The quick-burning Illinois coals are much less reliable in this respect.

(*20*). *Satisfactory regulation* is more readily accomplished with the eastern fuels and with coke than with the Illinois coal.

(*21*). *The total attendance* required may be considerably less when burning anthracite than the other fuels. The same may be said in general as between coke and Pocahontas as compared with the Illinois coal. This condition would be especially noticeable in connection with heating apparatus used in residence work.

(*22*). *Anthracite and coke* possess marked advantages over the other fuels, especially over the Illinois coal, with respect to cleanliness. They are in general cleaner in and about the boiler room and do not smoke, either from the chimney or in the boiler room. Little trouble is had with soot or ash in the flues and with reasonable care noxious gases should not be given off in the furnace room; also, the ash is small in amount and easily handled.

Clinkering may take place to some extent.

(*23*). *Pocahontas coal* is less clean to handle than anthracite or coke, makes some smoke, soot and other dirt and burns with a small amount of very easily handled ash which is not apt to clinker.

(*24*). *Illinois coal,* comparatively speaking, smokes badly, deposits a large amount of soot in the flues, may cause the emission of smoke and noxious gases into the boiler room. It is dirty to handle in and about the boiler room. The amount and performance of the ash in the fire-box vary considerably with different kinds of Illinois coal. In general, however, the ash is considerable in amount and clinkers to a greater or less extent, sometimes badly.

(*25*). *Washing and sizing Illinois coal* eliminate to a very considerable extent the objectionable features with regard to smoke, soot, dirt and ash just mentioned.

C. General

(*26*). *In considering house-heating boiler tests,* a number of important considerations, such as efficiency, fuel cost, attendance, control, cleanliness and equipment must be taken into account. The relative importance of such factors can not be stated definitely and varies greatly with the nature of the service required of any given installation.

(*27*). *Efficiency and fuel cost* may become the items of greatest importance where heating work is upon a comparatively large scale approaching power boiler conditions.

(*28*). *Simplicity and the ease* with which the heating apparatus can be cared for may be of greater importance than high evaporative efficiency.

(*29*). *The condition which requires the minimum amount of attendance* may be the most satisfactory and economical and more than offset the consumption of some extra fuel.

(*30*). *The ability to get up steam quickly,* and to maintain uniform pressure and fire conditions over comparatively long periods of time may be of greater importance than questions relating to either fuel or equipment.

(*31*). *The desire or necessity for cleanliness* with respect to smoke, soot, ash and dust or dirt in the boiler room, may warrant the use of high priced fuel.

D. *Method of Conducting Tests*

(*32*). *In general* the test should be made under conditions approximating those of the service which is required of the fuel and equipment. To do this will require tests of two kinds.

(*a*) *If the load demand is fairly constant and comparatively high*, test at the required load in a manner generally similar to that employed in power boiler work, making evaporative performance the main item sought.

(*b*) *If the load demand is very variable*, test under conditions approximately similar to operating conditions. In such tests questions relating to attendance, cleanliness and control will generally be found of equal or greater importance than those relating to efficiency and the tests should be so conducted as to give the fullest information possible along these lines.

(*33*). *Make the tests* classified under (*a*) of paragraph 32 at least 16 hours long and to consist of at least three firing charges of fuel.

(*34*). *Make the tests* classified under (*b*) paragraph 32, 24 hours long.

(*35*). *Use the standard method* for starting and stopping all tests, that is, start the test with a fresh fire and close it by drawing the fire and allowing for the residue of unconsumed fuel thus obtained.

(*36*). *No conclusions are offered* as to the best method of conducting tests for the purpose of determining the proper rating to be given to particular apparatus. Further tests to be reported upon later will, it is hoped, be of service in this connection.

3. *General Discussion of the Problem Relating to Tests of Fuel in House-heating Boilers*

(*1*). To determine the relative value of a fuel for different purposes or of different fuels for a given purpose, it generally seems advisable to make the tests in connection with the apparatus with which the fuels would ordinarily be employed, and under conditions at least approximately similar to those of every day practice. Laboratory methods, such as chemical analysis and calorific determination, are in general considered as only a part of a fuel test and are employed along with other data in interpreting the results. We thus have fuel tests made in connection with boilers, gas producers, coking ovens, furnaces, and other devices in order that the results and deductions may be applicable to the particular problem in hand. In any given branch of fuel testing this process of applying particular conditions may be carried still further.

(2). *Small heating units as compared with large units.*—The fuel tests here considered were made in connection with house-heating boilers of comparatively small size. On account of the small amount of available information relative to a satisfactory method for conducting house-heating boiler tests, one of the principal purposes in conducting these tests was to obtain information that would assist in developing such a method. Fuel tests with house-heating boilers will of necessity be similar, in many respects, to the tests made in connection with power boilers. While not overlooking the difference which must exist, due to the unlike conditions under which these two types of boilers operate, and the purposes for which each type is operated, it was deemed advisable as a first step in this work to make a series of tests upon house-heating boilers as nearly as possible by the methods which have been found satisfactory when testing with power boilers.

In work with the large units, fuel cost is generally the important factor, and the highest evaporative performance that can be obtained per dollar expended for fuel is the condition desired. Conditions relating to attendance, equipment, cleanliness and methods of operation are of secondary importance, and are capable of considerable variation or adjustment (depending upon the size and importance of the installation) in order to obtain a high rate of evaporation. Conditions surrounding house-heating boilers are, however, of such a nature that they can not be readily changed. Higher rates of evaporation and more efficient rates of combustion could, doubtless, often be obtained by having a fireman in constant attendance. The cost of such attendance is, however, in most cases prohibitive. The use of unusually expensive, complicated, or large apparatus is from the nature of the service undesirable. Conditions relating to equipment and attendance may be of so much greater relative importance than low cost of evaporation as to permit of relatively inefficient performance in order to satisfy those considerations. In many instances it will be found that the condition which requires the minimum amount of attendance is the condition which is most satisfactory and the advantage of simple, easily cared for equipment will more than offset the consumption of some extra fuel. It may be of much greater importance to get steam up quickly, or otherwise produce the desired heating effect quickly, and to be able to maintain a uniform rate of heat generation through a considerable length of time, than it is to furnish that heat at the lowest possible fuel cost. Such considerations may warrant the use of high-priced fuels or the sacrifice of evaporative efficiency for the sake of ease of fire control. Regulation, ease with which good fire conditions are maintained with respect to ash and clinker, the tendency of flues to become fouled, dirt in the form of dust, smoke, soot, or ash, whether from the coal pile, the fire-box, or chimney, are all important considerations aside from their relation to evaporative performance.

(3). *Outline.*—In order that the results of house-heating boiler tests may be of the greatest use, it becomes desirable to report more or less fully upon quite a number of conditions. The following outline presents most of the questions which will arise in making fuel tests with house-heating boilers.

Efficiency

(*a*) Evaporative performance, including efficiencies of the boiler and furnace, grate, and of the plant.

(*b*) Fuel cost for heat delivered.

Control

(*a*) Time required to get up steam pressure.

(*b*) Length of time of holding uniform pressure and satisfactory fire conditions without attention.

(*c*) Uniformity of regulation.

(*d*) Total attendance.

(*e*) Capacity.

Cleanliness

(*a*) Dust and dirt in boiler room.

(*b*) Ash and clinkers.

(*c*) Soot and ash in flue.

(*d*) Smoke.

(*e*) Smoke and gases in furnace room.

(4). *Relative importance of conditions.*—It is obviously impossible to measure exactly just what is the relative importance of the factors as above grouped under control and cleanliness, as compared with boiler efficiency and evaporative performance, but it is evident that they are of much greater relative importance when considering house-heating boilers than when considering power boilers. It is also true that the importance of certain factors will vary greatly according to the service rendered. In heating large school buildings with house-heating boilers the conditions may approximate very closely conditions in power work, and evaporative performance will be the item of greatest importance, while in the case of heating a small residence, cleanliness and ease of control may readily seem to be of first importance.

(*5*). *Capacity.*—The problem or problems in connection with each of the items mentioned are probably evident, with the possible exception of the item *capacity* which is listed under the head of control. In the case of a house-heating boiler, the question relative to capacity which is of importance, is how many square feet of radiation can be served by the boiler through comparatively long periods of time without attention, except at the time of firing. It is generally desired to know how many square feet of radiation can be served through a period of from six to eight hours without attention during that time. The same amount of fuel consumed within a short time should serve more radiating surface per hour than when burned during a longer period of time. The one hour period as employed in defining a horse-power, and as used in rating power boilers, is not satisfactory for comparative purposes in connection with house-heating boiler work. In this kind of work, then, in order that information relative to capacity may have the greatest usefulness, it should be based upon the evaporation which can be obtained during a period of from six to eight hours without attention, rather than upon the evaporation obtained in one hour with whatever attendance may be required. Thus a boiler rated at 1000 square feet should be capable of serving that amount of radiation without attention for a much longer time than one hour. In order to give satisfaction as a house-heating boiler, it should probably be able to serve that radiation for a period of at least six hours without attention during that time.

(*6*). *Purpose of tests.*—In carrying on the tests herein reported it soon became evident that it would be difficult to conduct tests so that suitable data concerning all of the above mentioned items could be obtained from any one test. Tests so run that the data would be of the greatest comparative value, for instance, in the case of the items grouped under efficiency, made the data concerning some of the items appearing under control and cleanliness, of little value in their relation to house-heating conditions. The lack of a satisfactory method of making tests, or of one generally accepted as such, was apparent. Under these circumstances it was deemed advisable to make a series of tests according to the A. S. M. E. code for conducting boiler trials. Accordingly, the tests herein reported have been, in the main, run in accordance with the recommendations contained in that code. The purpose of the tests thus becomes twofold; first, to obtain the information usually obtained from boiler trials when operating upon house-heating boilers, with various types of fuels; second, to obtain information that might assist in developing satisfactory methods for conducting house-heating boiler trials. The second end, it was thought, could best be attained by at first making use of the A. S. M. E. code. The adoption of this code as a guide in conducting the tests tends to lay the greatest stress upon questions relating to evaporation and efficiency. While not overlooking the importance of questions relating to capacity, regulation, attendance, and cleanliness, conditions were so arranged as to make evaporative performance the main item sought, and the best basis of comparison for this particular series of tests. It is, however, intended to conduct several additional series of tests in which more attention may be given to some of the other items just mentioned.

(7). *Variable conditions.*—Fuel or steaming tests in connection with boilers as small as the average house-heating boiler, and especially when carried on under the average conditions under which such boilers are operated, present difficulties which are much more pronounced than when conducting similar trials upon larger apparatus. The low rate of combustion under ordinary circumstances, and the low capacity at which the average house-heating boiler is operated, either all or part of the time, tend to make the results of different tests unsatisfactory for purposes of comparison, as it is exceedingly difficult under these circumstances to obtain uniformity of conditions between different tests. Apparently slight variations in fire conditions might have considerable influence upon results.

(8). *Amount of fuel consumed.*—The determination, with sufficient exactness, of the amount of fuel consumed presents difficulties in the case of small apparatus which are not encountered to the same extent with larger apparatus. The quantities of coal burned and water evaporated for tests of equal length may easily be ten or twenty times as large when testing with a power boiler as when testing with a house-heating boiler, and errors in determining these quantities may readily be a much greater percentage of the total in the case of the small boilers. Errors of this kind are in general most likely to occur at the beginning or end of the test, as in judging the amount of fuel consumed, or determining the weight of the water in the boiler. Probably the most noticeable error of this kind is to be found in the usual or so-called alternate method of starting and stopping boiler trials. The alternate method of the code of the American Society of Mechanical Engineers for conducting boiler trials provides for beginning and ending the test when the fire conditions are such that equal amounts of unconsumed combustible and of ash are upon the grate for the two times under consideration. That this condition may be met requires judgment and careful operation. In the average power boiler trial the fuel burned and ash removed amount to many times that which may be upon the grate at the start or stop of the test, and a mistake in judging the fire conditions at those times will make a comparatively small error in subsequent calculations. This, however, is recognized as a possible source of error of considerable importance, under the most favorable conditions, when testing power boilers. In the case of very small boilers, especially in those having a comparatively deep fire bed such as is often used in house-heating boilers, the quantity of fuel upon the grate at the beginning and end of a test would be a very considerable proportion of the total fuel burned, unless the test was of considerable length. About the same assumptions with regard to the two types of boilers would show that the error expressed in per cent of fuel consumed might readily be four or five times as great in the case of the house-heating boilers as in the case of the power boilers.

(9). *Standard method for starting and stopping test.*—This difficulty can be met in two ways. The test can be made longer, in which case the error becomes correspondingly smaller as expressed in per cent, or a method of starting and stopping the test can be employed, intended to eliminate or diminish the error. The standard method of the code of the American Society of Mechanical Engineers provides for the raising of steam pressure by means of a preliminary fire, withdrawing that fire and beginning the test with a new fire built with a known weight of fresh wood and coal. At the end of the test, the fire remaining is drawn and allowed for in subsequent calculations. When testing power boilers the standard method occasions some additional work and trouble, and there is considerable difference of opinion even among experts as to which method, the alternate or the standard, is the better. By far the greater number of boiler trials are probably begun by the alternate method, on account of that being the more convenient, and because of this lack of definiteness as to which method is the better. In the case of the house-heating boiler the comparatively large amount of fuel upon the grate; the lack of uniformity of fire conditions at different times during the test; the difficulty of duplicating fire conditions as desired; and the difficulty of accurately estimating the amount of unconsumed fuel and ash in the fire-box, make the alternate method of starting and stopping unsatisfactory, and necessitate some plan more in accordance with the standard method, in order that the fuel consumed may be determined with sufficient accuracy.

(*10*). *Tests by societies and individuals.*—Societies and individuals interested in this kind of work have from time to time reported tests, or discussed methods for making such tests, but apparently without making definite recommendations that have been found satisfactory for the guidance of others, or that have been adopted generally enough to make comparisons possible or of value. The number of tests of this kind which have been reported is surprisingly small as compared with the number of tests conducted upon power boilers. Probably the greatest amount of work in this line has been done by the manufacturers of heating apparatus. The results of their investigations are, however, either not available or are applicable to particular makes of apparatus only, rather than to the problem as a whole.

4. *Fuel*

Table 1 presents in tabulated form the different kinds or types of fuels tested, the section of the country from which they were received, and their size.

TABLE 1

DESCRIPTION OF FUELS TESTED

Kind or Type of Fuel	Commercial Name	Size inches	Source of Fuel
Anthracite	Egg	2¾ to 2	Wyoming District, Pa
Pocahontas	Lump	*	Mercer County, W. Va
Coke—Gas-house by-product	Crushed	3½ to ¾	Mnfd. by U. & C. Gas Co., from Youghiogheny coal
Coke—Solvay process	Crushed, Nut size.	1¾ to ¾	Obtained from Chicago market
Illinois	Nut	1¾ to 1	Williamson County
Illinois	Screened lump	*	Macon County
Illinois	Screened lump	*	Vermilion County

* All large lumps were broken to pieces 6 inches or less in diameter.

The fuels here listed are fairly representative of those used in house-heating work in the state of Illinois, namely: anthracite coal, eastern bituminous coal, coke and Illinois coal. The Illinois coals are typical of those most commonly used in this section of the State, coming from the southern, eastern, and central portions of the State. These fuels were purchased in the local market, either Champaign or Urbana, in lots of three tons or less, with the exception of the Solvay coke, which was obtained from the Chicago market. The anthracite and the Illinois coal from Macon County were, judging from the appearance, rather below the average quality of coal of these kinds as they appear in this market. Chemical analyses, given in Table 12, page 74, Appendix A, give more exact information as to the exact composition of all of the fuels used. Taken as a whole, however, judging from general appearances, these fuels were fair samples of what the average householder might expect to obtain.

5. *Methods of Conducting Tests*

(*1*). *Starting and stopping the test and handling the fire.*—The methods recommended by the A. S. M. E. code for conducting boiler trials were in general followed in conducting these tests. The tests varied in length from 7.97 hours to 26.53 hours. With each fuel, tests approximately 8, 16, and 24 hours long were made upon each of the two boilers. The standard method of starting and stopping the trials as prescribed by the A. S. M. E. code was used. Steam pressure was raised by means of a preliminary fire, and the boiler run at a pressure of at least five pounds for a short time to insure fairly uniform conditions in and around the boiler. The preliminary heating usually required about one hour. At the start of the tests the preliminary fire was rapidly removed and a fresh fire started with a weighed amount of wood and the first charge of coal. The test was started when the wood was ignited, at which time observations of time, water-levels, and pressures were taken. The kindling and entire amount of first charge of coal were ordinarily fired before the fire was lighted. The only exceptions to this were in cases where the kindling was ignited by the hot grates before all of the coal was fired. This, however, only delayed the firing of the entire charge of coal a few minutes after the start of the test. In all tests made with Boiler D_1, 75 lb. of fuel were fired at a time, and in all tests made with Boiler D_2, 105 lb. of fuel were fired at a time. These amounts, as compared with each other, are closely proportional to the grate surfaces of the two boilers. On account of all fuel charges being the same in amount, and also on account of the fact that a test was not ended until the fuel was so completely burned that pressure could no longer be maintained, many of the tests varied considerably from the 8, 16, or 24-hour period under which they are classed. A pressure of approximately five pounds was carried on the boiler. After a charge of fuel had been fired, the fire was not again touched until the next firing, if the automatic regulation was sufficient to keep up steam pressure without other attention. In case it became necessary in order to maintain pressure, there being plenty of unconsumed fuel in the furnace, the fire was poked or otherwise worked as seemed desirable.

(*2*). *Method of firing.*—For the tests with anthracite, coke and Pocahontas coal the fuel was fired by the spreading method, that is, the fresh fuel was spread about evenly over the entire grate surface. For the Illinois coals, on account of the liability of explosions due to gas collecting in the combustion chamber and flues, it was deemed advisable to fire by a method approaching the coking method. With the boiler D_1 the fresh fuel was fired more heavily at one side of the furnace than at the other, allowing the fire to burn up brightly much more quickly upon the side thinly fired than would otherwise have been the case. With boiler D_2 the burning fuel which remained in the furnace just before firing, was in part pushed or raked toward the rear of the grate, and the greater part of the fresh charge fired in front. This allowed the fire upon the back part of the grate to burn brightly almost from the time of firing.

(*3*). *Attention.*—The effort was made throughout to reduce to a minimum the amount of attention given the fire between times of firing. The attention which the fire did receive, however, which might be considered as additional to what would be expected in ordinary house-heating work, was given in accordance with the desire to have the tests fairly comparable upon an evaporative performance basis, rather than to obtain data relative to attendance conditions.

(*4*). *Ash and residual fuel.*—The fire was drawn at the end of the test, when the boiler pressure dropped below four or five pounds on the last firing, and did not again rise upon the opening of the damper and the closing of the check. Just as the grate was dumped, final observations concerning time, water, temperatures and pressures were taken. The material drawn out at the close of the test was immediately put into a galvanized can with a close fitting cover to prevent further combustion. Analysis of this partly consumed or residual fuel furnished suitable corrections in the determination of the amount of fuel actually burned. The ash was kept separate from the residual fuel, being taken from the furnace and ash-pit before the fire was drawn.

(*5*). *Sampling of fuel, ash and residual fuel.*—The fuel was sampled in the usual manner by taking a small portion from each firing. The sample so collected varied from about 5 per cent to 10 per cent of the total fuel fired. It was collected in a can with a closely fitting cover, and, within a few hours after the close of the test, was thoroughly mixed, crushed to ¼ in. size or smaller, and quartered until a 1000 gram sample was obtained. This 1000 gram sample, placed in a suitable pan, was air-dried and then transferred to the Chemical Laboratory in glass jars for the purpose of chemical analysis.

The ash and residual fuel were each run through a laboratory crusher reducing them to pieces ¼ in. or smaller. They were then quartered, accompanied with thorough mixing, until samples were obtained of each, which would about fill a one quart glass jar.

(*6*). *Chemical analyses.*—All chemical analyses were made at the chemical laboratories of the University of Illinois. Proximate analyses and calorific determinations of the fuel were made for each test or for each group of two tests, where the two boilers were operated simultaneously upon the same fuel. The ash and residual for each test were analyzed for carbon and earthy matter. Ultimate analyses were made from composite samples for each fuel tested. The composite samples were made by combining from each of the air-dried samples an amount proportional to the fuel burned as represented by each sample. Calorific determinations were made in a Mahler-Atwater oxygen calorimeter. In Table 12, page 70, will be found analyses of the ash and residual fuel as to carbon and earthy matter, and the proximate analyses of the fuel for each test.

In Table 2 are given the proximate and ultimate analyses of the fuels as made from the composite samples.

TABLE 2

ANALYSES OF COMPOSITE SAMPLES

Per Cent

Kind of Fuel	Proximate Analysis Fuel as Fired				Ultimate Analysis Dry Fuel					
	Fixed Carbon	Volatile	Moisture	Ash	Carbon	Hydrogen	Oxygen	Nitrogen	Sulphur	Ash
Anthracite	77.68	7.07	3.47	11.78	81.33	2.12	1.82	0.91	1.61	12.21
Pocahontas	73.43	19.50	1.90	5.17	84.20	4.79	3.61	1.14	1.00	5.26
Gas House coke	81.74	2.74	5.73	9.79	86.05	0.83	0.41	0.91	1.41	10,39
Solvay coke	85.76	2.45	1.51	10.28	86.84	0.58	0.28	1.21	0.65	10.44
Illinois, Williamson county	48.42	36.28	6.66	8.64	71.62	5.19	10.29	1.53	2.11	9.26
Illinois, Macon county	40.56	37.67	10.01	11.76	66.98	4.63	10.34	1.42	3.56	13.07
Illinois, Vermilion county	40.35	39.57	11.14	8.94	73.22	4.43	8.29	1.52	2.48	10.06

TABLE 3

AVERAGE PROXIMATE ANALYSES OF FUEL AS FIRED

Per Cent

Kind of Fuel	Fixed Carbon	Volatile Matter	Combustible (Carbon+Volatile)	Moisture	Ash	Sulphur	Calorific Value B. t. u. per lb.
Anthracite	78.55	5.77	84.32	3.93	11.75	1.17	12682
Pocahontas	73.33	19,49	92.82	2.01	5.17	0.98	14753
Gas House coke	80.68	3.34	84.02	5.92	10.06	1.15	12053
Solvay coke	85.80	2.14	87.94	1.60	10.46	0.65	12505
Illinois, Williamson county	48.07	36.27	84.34	6.55	7.27	2.09	12275
Illinois, Macon county	40.84	37.56	78.40	10.24	11.36	3.19	11005
Illinois, Vermilion county	40.36	39.53	79.89	11.18	8.93	2.21	11546

Table 3 gives values for the proximate analyses of the different fuels obtained by averaging the values for all tests with each fuel. The averages included in this table are computed by giving weights to the values for each test proportional to the weight of fuel fired. A comparison of the average values for each fuel, as contained in this table, with the corresponding values of the proximate analyses made upon the composite samples exhibits some differences which are, however, for the most part, small. The average calorific value, determined for each fuel in the same manner as the other averages has been included in Table 3.

(*7*). *Feed water.*—The feed water delivered to each boiler through the measuring tanks was condensation from heating coils, and the effort was made to feed the water at as nearly constant a rate as possible, and at a temperature which might correspond fairly well with that of the returns in house-heating work. The feed water temperature averaged about 175° F.

(*8*). *Loading.*—For all tests a load equivalent to about 65 per cent of the boiler rating was maintained by means of a suitably sized orifice in the outlet. The evaporation of 0.3 lb. of water from and at 212° F. was assumed as equivalent to serving one sq. ft. of radiation for one hour. A pressure of 5 lb. controlled by the automatic regulators, which are a part of the boilers, was maintained at the boiler. The pressure after leaving the boiler was reduced to slightly over 2 lb. in the receiver, so that a difference of 2 lb. pressure was maintained between the two sides of the orifice. Recording gages were used in order that the variations in boiler pressure might be readily observed during the course of the test.

(*9*). *Temperatures.*—A recording pyrometer was used in connection with most of the tests made upon Boiler D_1, for the purpose of taking flue gas temperature. For the remainder of the tests upon boiler D_1, and for all tests upon D_2, mercury flue gas thermometers reading to 1000° F. were employed. A recording thermometer for outdoor temperatures was also employed.

(*10*). *Smoke and flue gas analyses.*—Smoke records were taken for each test, generally for a period extending from the time of one firing to the time of the next firing. The flue gas samples were, as a rule, taken as continuous samples, each over an interval of time of one hour. At times continuous samples were taken extending over the entire time between two firings. These samples were analyzed in an Orsat apparatus of the common type.

(*11*). *Cleaning flues.*—The boiler flues were cleaned previous to each test in order that conditions in this respect might be approximately equal. On account of the preliminary fire, there was doubtless always some soot on the flues at the start of the test proper, as it was not considered advisable to open up the boiler for cleaning just before starting the new fire. Also the flues, doubtless, became coated with soot more rapidly with some fuels than with others. There would also, as a general rule, be a greater accumulation of soot and ashes in the flues for a sixteen or twenty-four hour test than for an eight hour test.

(*12*). *Miscellaneous observations.*—The following observations were taken every twenty minutes: height of water in the boiler, height of water in the feed tank, height of water in gage glass of separator, temperature of feed water, boiler room temperature, steam pressure in boiler, difference of pressure on the two sides of the orifice plate, and drafts in ash-pit, over the fire and in the flue.

6. *Test Data*

The test data were, in general, recorded in accordance with the requirements of the A. S. M. E. code and were entered upon blank forms suitably arranged for the class of work in hand.

On pages 84, 85, 86, and 87, of Appendix A will be found, Fig. 18-21, graphical logs of four tests which have been selected as representative. They are, respectively, records of tests made with anthracite, Pocahontas coal, coke and Illinois coal.

7. *Tabulated Data and Results*

In Appendix A, Table 12, will be found the principal data and results of the 48 tests under consideration; explanatory matter concerning the results accompanies the table. This material will be found upon pages 66 to 83, inclusive, of Appendix A.

In Tables 13 and 14, pages 88 and 89 of Appendix A, will be found data relative to flue gas analyses. It will be noted that the per cent of CO_2 is in general quite high. In all flue gas analyses the per cent of CO was also determined in the manner usual with the Orsat apparatus. Owing to the uncertainty as to the value of such determination these data are not here presented. In general no trace of CO was found or only a fraction of 1 per cent.

In one case, however, where the sample was taken immediately after firing, 4.3 per cent CO was found.

8. *Method of Calculating Results* The results tabulated in Table 12, Appendix A, are in general calculated by methods which are the same as those employed in calculating boiler trials made under the A. S. M. E. code.

Throughout all calculations involving capacity the evaporation of 0.3 pounds of water from and at 212° F. has been used as equivalent to serving one square foot of radiation for one hour.

In the calculation of item 23.2 tabulated on page 72, which is the total dry fuel fired minus the dry fuel equivalent of the ash and of the residual fuel, it was assumed that the ash and the residual fuel consisted of earthy matter and carbon only. The carbon found in the ash and the residual fuel by analysis was assumed to have a heating value of 14600 B. t. u. per lb. and was converted to dry fuel by dividing the total number of B. t. u. so found by the B. t. u. value of one pound of dry fuel under consideration.

9. *Discussion of Results*

A. Efficiency and Evaporative Performance

(*1*). *Efficiency and fixed carbon content.*—An examination of item 62 as given in Table 12, page 82, shows that the plant efficiencies varied from 44.76 per cent to 66.21 per cent. In Fig. 1 these efficiencies have been plotted for each test to a base, expressed in per cent, of the fixed carbon content of the coal. These points fall into two groups due to the low fixed carbon content of the Illinois coals as compared with the other fuels. The tendency of low efficiency to go with low fixed carbon content is, however, marked, and emphasizes the fact that in this respect the fuels high in fixed carbon content are much better adapted to present methods of house-heating. The Illinois coals may be considered as the natural fuel supply for this state and section and the problem becomes one of adapting methods and equipment to the burning of these coals at efficiencies at least approximating those of fuels like anthracite and coke.

(*2*). *Efficiency with Pocahontas coal.*—The lowest plant efficiences recorded are for tests made with Pocahontas coal. The average plant efficiency with Boiler D_1 for this fuel was 44.97 per cent and with Boiler D_2 55.43 per cent. A partial explanation of

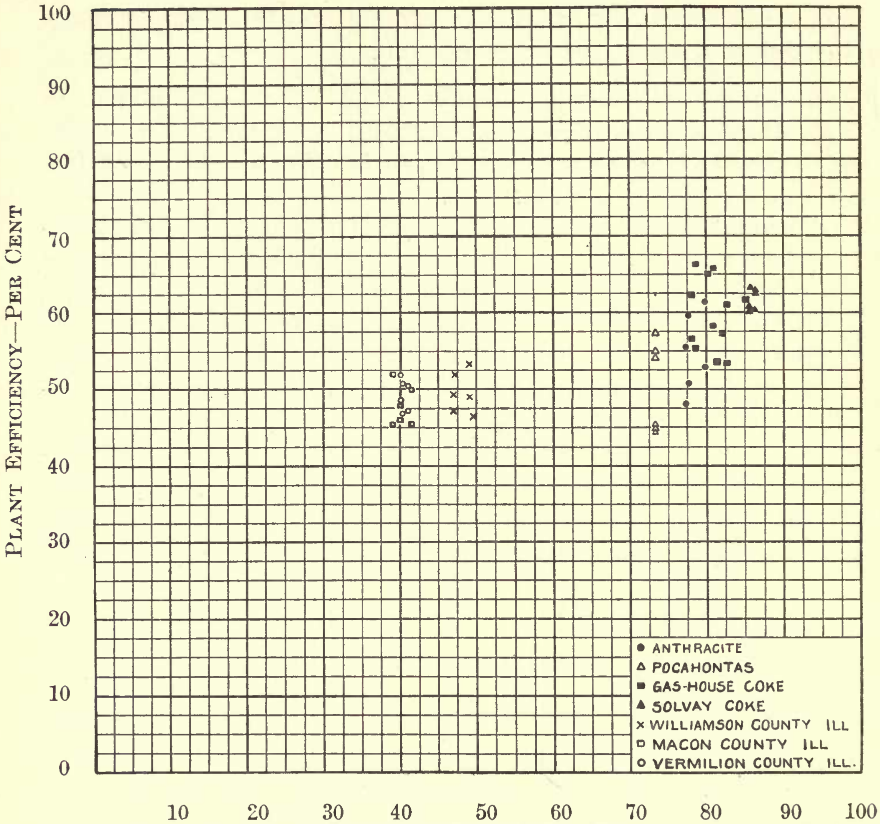

Fig. 1 Relation of Efficiency to Fixed Carbon

these low plant efficiencies for the Pocahontas coal is to be found in the fact that a comparatively large amount of unconsumed fuel passed through the grate with the ash. The per cent of carbon in the ash for Pocahontas tests varied from 50 to 70 per cent, being much higher than with any other fuel tested. The Pocahontas coal used contained a large amount of very fine coal which is the usual condition of this fuel in this market.

The efficiency of the boiler and furnace alone, excluding the effect of coal dropping through the grate, is, however, also low in the case of the Pocahontas coal. These efficiencies will be found under item 61, Table 12, page 82 and average values of the same in Table 6, page 36. The use of Pocahontas coal for house-heating purposes is quite common in this section and when used is generally highly thought of for such work, having merits that may warrant its use in spite of low evaporative efficiency. Of the several fuels tested it has the highest heat content as expressed in B. t. u. contained. The small number of tests here reported precludes the possibility of drawing definite conclusions in regard to the efficiency that may be obtained with this fuel under the various conditions under which it may be consumed, while the wide variation in the efficiencies obtained, especially as between the two boilers, indicates the possibility of adapting fire conditions and equipment to the requirements of the fuel in order to obtain higher efficiencies.

(3). Efficiencies of the two types of boilers.—There has been no attempt in this article to compare or discuss the merits of the boilers used in making the tests, the tests having been conducted with the idea of comparing the fuels rather than the apparatus. In the case of Pocahontas coal, as mentioned above, it was found that one boiler was operating much more efficiently (measured by evaporation) than the other. When testing the two kinds of coke it was found that in the case of the Solvay coke the efficiencies for the two boilers were not greatly different, while when testing with the gas-house coke they differed greatly. It will be noted that in the tests reported there are six tests with each fuel except in the case of the gas-house coke, with which fuel twelve tests were made. The series of tests upon the gas-house coke was duplicated as a check in regard to this difference in performance. The coke was chosen as being a fuel with which constant fire conditions could be readily maintained and with which any discrepancy would be most easily detected, although the difference in efficiency as between the two boilers was the most marked in the case of Pocahontas coal. The second set of tests with the gas-house coke did not show material differences in regard to efficiencies from those shown by the earlier tests. The principal difference between the two cokes, aside from a slightly higher volatile content in the gas-house coke was the smaller and much more uniform size to which the Solvay coke was crushed. Fire conditions were much more uniform when burning the Solvay coke and it seems probable that efficiencies were much more affected by varying chemical or physical characteristics of the fuel in the case of the boiler with the comparatively small amount of heating surface.

(*4*). *Variations in efficiency.*—Efficiencies as determined by fuel tests with house-heating boilers apparently vary greatly with varying conditions of fuel and fire and should be compared only with the greatest care. Omitting considerations which relate to the boiler and furnace employed, the composition of the fuel is probably the most important factor to be considered. A coal high in fixed carbon so that combustion may be completed on or near the grate will give high efficiencies, a coal high in volatile matter which, when burning, gives off large volumes of rich gases that may or may not be burned, will give low efficiencies. The high volatile fuels are, as a rule, of approximately the same calorific capacity as the high carbon fuels, while if based upon the cost per B. t. u. they are much cheaper. The problem in this particular respect (not considering cleanliness, control, etc.) then becomes one of determining the conditions which will permit of burning the high volatile coals at efficiencies at least approximately equal to those of the high carbon coals, or stated somewhat differently, the conditions which will permit of burning Illinois coal, the cheap and natural supply, instead of the fuels which must be transported long distances and sold at correspondingly high prices. For the tests here considered it is believed that decided differences in efficiency were caused by various fire conditions due to the size of fuel burned and to the per cent of fine material contained therein, to the degree with which the fire bed coked, burned evenly over the grate or burned holes through and around itself, also to the extent to which the gases first distilled from a fresh charge of fuel were burned or passed away unconsumed. While efforts were made throughout the tests to keep fire conditions uniform, it not being the purpose of the tests to study efficiency under varying conditions, such variations as did occur point to the possibility of improving efficiency by proper attention to details relating to fuel, operation and equipment.

(*5*). *Efficiencies as compared with those of power boilers.*—Under conditions comparable to the tests made efficiencies ranging from 40 per cent to 70 per cent may be expected. These efficiencies are somewhat, though not greatly, lower than corresponding figures upon power boilers.

(*6*). *Illinois coal.*—The efficiencies obtained indicate the desirability of improvement in order that Illinois coal may be placed more nearly on an equal footing with other fuels in this respect when employed for house-heating purposes.

(7). *Evaporative performance.*—The equivalent water evaporated from and at 212° F. per sq. ft. of heating surface varied in the case of boiler D_1 from 3.36 lb. to 3.91 lb. and in the case of boiler D_2 from 2.48 lb. to 2.89 lb. If these small boilers were rated upon 10 sq. ft. of heating surface to 1 b. h. p., which is equivalent to an evaporation of 3.45 lb. per sq. ft., when operating at 100 per cent capacity, then boiler D_1 under the test conditions was evaporating water at quite as high a rate as is usual in power boiler work, while boiler D_2, owing to its greater heating surface, was evaporating water at a somewhat lower rate, but still at one which is by no means uncommon in ordinary power boiler work. When it is remembered that these boilers were operating at approximately 65 per cent of their rated capacity it will be seen that high rates of evaporation would be required if they were operated at 100 per cent rated capacity, or if forced to an overload. The variable demand upon the house-heating boiler will at times necessitate very high or very low rates of evaporation per square foot of heating surface, and the nature of the service may readily warrant somewhat inefficient performance under these conditions in order that the equipment be comparatively small, simple in construction and easily operated. It would appear, however, that a rate of evaporation much higher than has been found economical or advisable in power boiler work should also be avoided in house-heating boiler work if that be possible, and the effort should be made to so adapt the fuel and equipment that a rate of evaporation would be obtained which under average operating conditions would be most apt to be accompanied by high efficiency.

(8). *Average operating conditions.*—The conditions under which house-heating boilers operate are so varied that it is impossible to state any given per cent of their rated capacity as even approximately that of average operating conditions. A boiler used for heating an office building, school house, or in work of a similar character might be operated at a relatively high average capacity as high or higher than 65 per cent as obtained in the tests under consideration, while in residence work on a small scale a boiler may only be required to operate at a high capacity for a few hours each day and the average load may not be more than 20 per cent of the rated capacity.

(*9*). *Efficiency and capacity.*—The arrangement and amount of heating surface advisable for low capacities may be unsuited for high capacities and deductions in regard to any particular feature of house-heating boiler performance must be made with regard for such conditions. The tests here considered have all been run at practically one capacity (65 per cent of the rated capacity) and give little information in regard to efficiency as affected by varying capacity. The uniformly lower efficiency of boiler D_1 as compared with boiler D_2 with the corresponding high evaporation per square foot of heating surface would indicate that high rates of evaporation per square foot of heating surface due to reduced heating surface tend toward low efficiency at least in the neighborhood of the capacities at which the tests were run. A series of tests is now under way operating these boilers at capacities varying from about 10 per cent to 100 per cent of their rated capacity in order to throw further light upon the relation of efficiency to capacity. The rated capacities of D_1 and D_2, 800 and 1075 square feet of radiation, respectively, are closely proportional to the fuel capacity of the fire-boxes, while the ratio of capacity (expressed in square feet of radiation) to the total heating surface is much higher in the case of boiler D_1 than of D_2, that is, when operating at full capacity one square foot of heating surface in boiler D_1 must serve 18.2 square feet of radiating surface while for boiler D_2 one square foot of heating surface serves only 14.2 square feet of radiation. The ratio of direct to total heating surface is higher in the case of D_1 than of D_2.

B. Length of Tests and Method of Conducting

In order to determine what length of test was best in order to secure data of a satisfactory character, tests of eight, sixteen, and twenty-four hours were run with each fuel upon each boiler. The principal item affected by the length of the test is the amount of fuel consumed, which in turn affects many of the other important calculated items. The difficulties attending the determination of the amount of fuel consumed have been discussed and the manner in which the longer test tends to eliminate the errors which occur.

(*1*). *Fuel consumption.*—Fig. 2-5, pp. 27-30, show the coal as fired, plotted on a time base, for each test made with four of the fuels tested. In all cases the slope of the coal line representing the period of the first charge of fuel is steeper than the slope of the line of subsequent firings. This is particularly marked in the case of the anthracite. An examination of the line

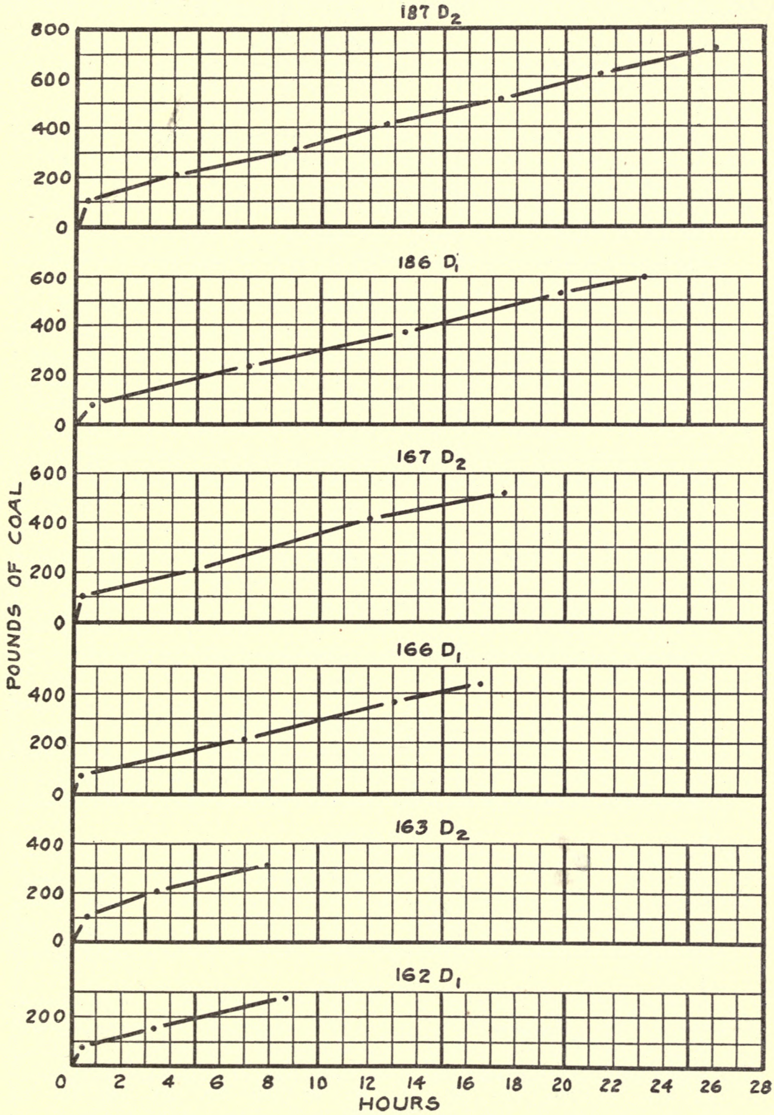

FIG. 2 FUEL CONSUMPTION—ANTHRACITE COAL

representing the second firing will in some cases disclose the fact that some unconsumed fuel remained in the fire-box at the time of the second firing and was then burned, making that period somewhat longer than subsequent periods. The time of the last

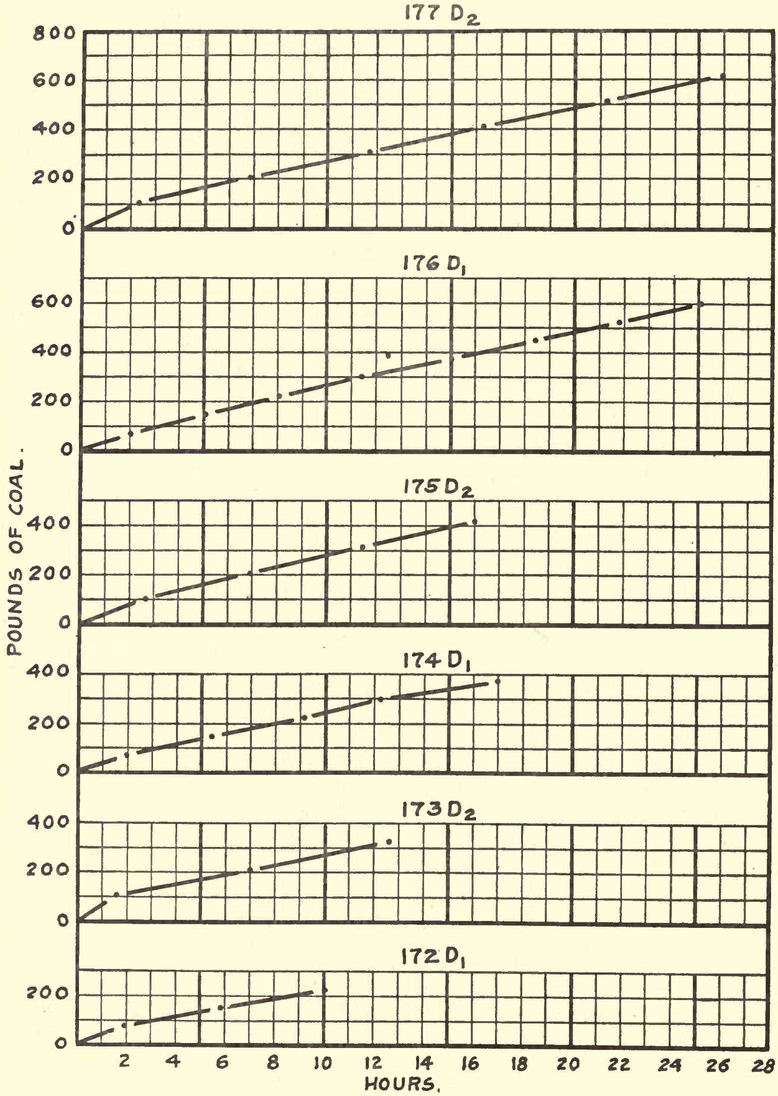

FIG. 3 FUEL CONSUMPTION—POCAHONTAS COAL

firing will also be noted as often being longer than the preceding periods on account of the fire being allowed to burn out somewhat more completely at the end of the test than was usual at the end of the other firing periods. As a rule, however, after the first firing the slope of the coal line is quite uniform, and it was the general opinion of the observers that after the first or second

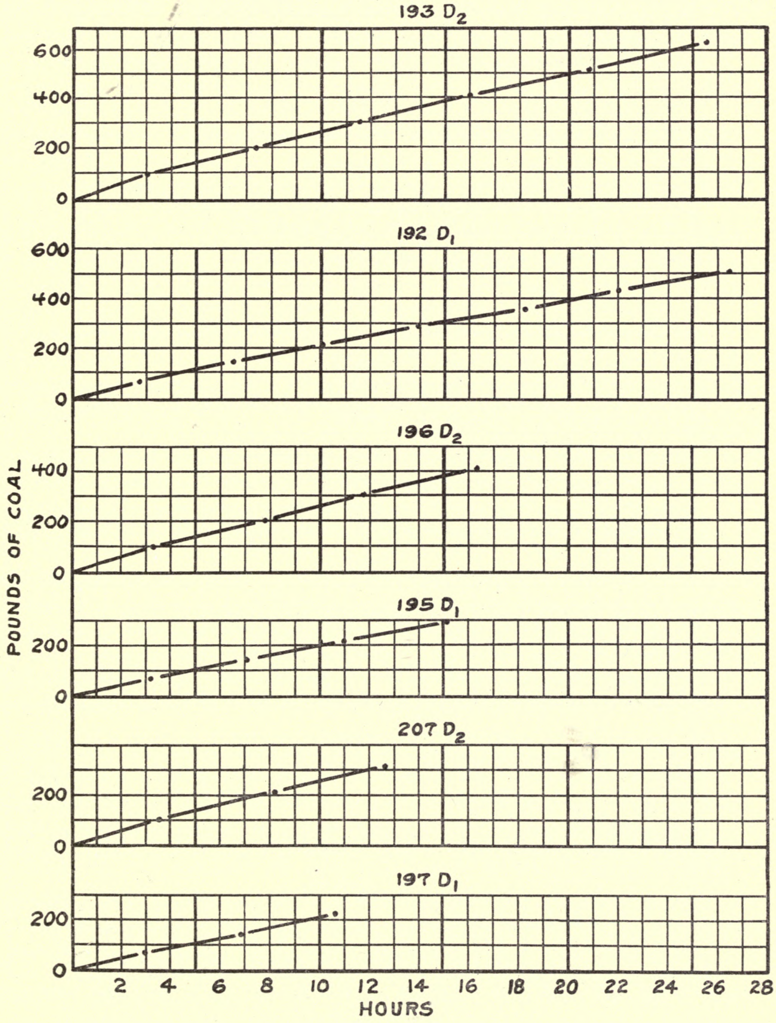

FIG. 4 FUEL CONSUMPTION—SOLVAY COKE

firing period the test conditions could readily be kept practically uniform for any reasonable length of time. At the beginning of this series of tests it was thought possible that after making the

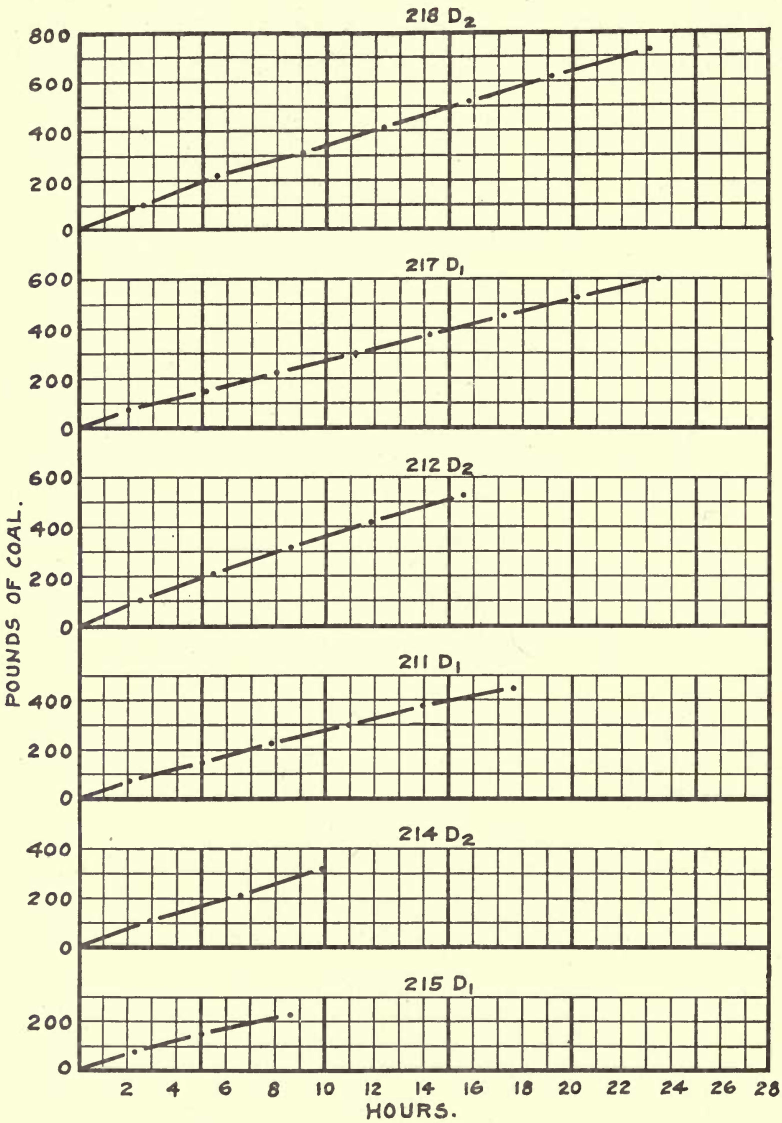

FIG. 5 COAL CONSUMPTION—ILLINOIS COAL (WILLIAMSON CO.)

tests, starting and stopping by the method adopted, it might be possible to divide the data so as to omit one or more of the firing periods, such as the first, or first and last periods, retaining only those periods as a portion of the test during which conditions were apparently constant. This would in effect give a test using the alternate method of starting and stopping. It has, however, not been thought advisable to attempt such a division of the data and discussion of it here. Many of the tests consisted of but three or four firing periods and the elimination of one or more periods would make the duration of the test extremely brief and correspondingly magnify errors due to the varying fire conditions. The methods adopted for determining the amount of fuel consumed were found to be very satisfactory and it seemed that little or nothing was to be gained by discussing the data upon a basis which might give less accurate values for that important item.

(2). *Efficiency and evaporation as affected by length of test.*— Table 4 shows the equivalent evaporation and efficiencies for all tests, grouped as tests 8, 16 and 24 hours long. The same data are plotted in Fig. 6 and 7. In the majority of the tests the rates of evaporation and efficiencies are higher for the 16-hour tests than for the 8-hour tests. This condition is true to a more marked extent in the case of boiler D_1 than of boiler D_2. The lower efficiencies, in general, of the 8-hour tests may be due to losses incurred through inefficient burning during the first fire which would affect the results of the shorter tests to the greater extent. Accumulations of soot in the flues of boiler D_2 and the extent to which this soot was burned out during the tests may have affected efficiencies to a considerable extent. Comparing the rates of evaporation and efficiency for the 16-hour and 24-hour tests the differences are in general not so great as between the 8 and 16-hour tests.

No complete explanation is here offered as to the cause of this variation in the matter of efficiency and rate of evaporation per pound of fuel for tests of different length. In some individual tests varying conditions which were noted were thought to have caused these changes either in part or altogether, but no general conclusion in this respect could be drawn. It was, however, considered that 16-hour tests would give results more reliable and better for comparative purposes than 8-hour tests and that as be-

TABLE 4

EQUIVALENT EVAPORATION AND EFFICIENCY FOR DIFFERENT LENGTHS OF TESTS

	8-hour Test			16-hour Test			24-hour Test		
	Length of Test	Equivalent Evaporation Per Pound of Fuel as Fired	Efficiency of Plant	Length of Test	Equivalent Evaporation Per Pound of Fuel as Fired	Efficiency of Plant	Length of Test	Equivalent Evaporation Per Pound of Fuel as Fired	Efficiency of Plant
	hours	pounds	per cent	hours	pounds	per cent	hours	pounds	per cent
BOILER D1									
Anthracite	8.77	6.32	48.07	16.55	6.67	50.58	23.15	6.68	52.59
Pocahontas	10.07	6.84	44.76	17.03	6.90	45.18	25.13	6.87	44.98
Gas House Coke	8.43	6.65	53.43	15.83	6.74	53.33	23.70	7.08	56.46
Gas House Coke	9.57	6.69	55.23	17.15	7.15	57.26	26.23	7.19	58.16
Solvay Coke	10.63	7.75	60.47	15.17	8.02	62.58	26.53	7.85	60.32
Illinois, Williamson county	8.63	5.86	46.42	17.68	6.05	47.17	23.48	6.19	48.99
Illinois, Macon county	9.78	5.19	45.46	16.73	5.24	45.94	24.58	5.18	45.53
Illinois, Vermilion county	7.97	5.53	46.88	16.45	5.78	47.14	24.47	5.73	48.50
BOILER D2									
Anthracite	8.00	7.26	55.22	17.52	7.87	59.68	26.00	8.01	61.23
Pocahontas	12.65	8.25	53.99	16.05	8.38	54.87	25.93	8.77	57.42
Gas House Coke	11.85	8.02	66.21	15.55	7.99	61.51	24.85	8.12	65.69
Gas House Coke	11.70	7.99	65.05	14.92	7.72	61.08	24.17	7.80	62.20
Solvay Coke	12.58	8.29	63.27	16.32	8.11	63.28	25.55	7.87	60.47
Illinois, Williamson county	9.88	6.61	51.93	15.58	6.33	49.35	23.18	6.73	53.26
Illinois, Macon county	8.38	5.93	51.95	16.03	5.48	48.04	23.13	5.71	50.18
Illinois, Vermilion county	8.55	5.97	50.61	15.07	6.18	50.40	25.02	6.12	51.80

tween tests 16 and 24 hours long the results of the shorter tests would in general be as serviceable as those of the longer ones.

(*3*). *Length of test required.*—Basing a conclusion as to the length of test desirable upon the work here reported for tests which are comparable to these tests as to load conditions, that is, operating at fairly high capacity, as 50 per cent or more of rated capacity, it would seem advisable to make the test at least 16 hours long and to have at least three firing charges. The stop should be made according to fire conditions, rather than at the end of a given interval of time. In case the firing charges were large or the load light, the length of the test might with advantage be somewhat longer than 16 hours. The length of 16 hours is given as approximately the minimum time which would give results that could be considered as satisfactorily comparable. Under the test conditions the 8-hour tests were liable to be considerably affected by the varying fire conditions at the start and stop of the test, while it seemed that after about 16 hours little was gained by running the test through 24-hour or longer periods. It is likely, however, that for service tests with very variable

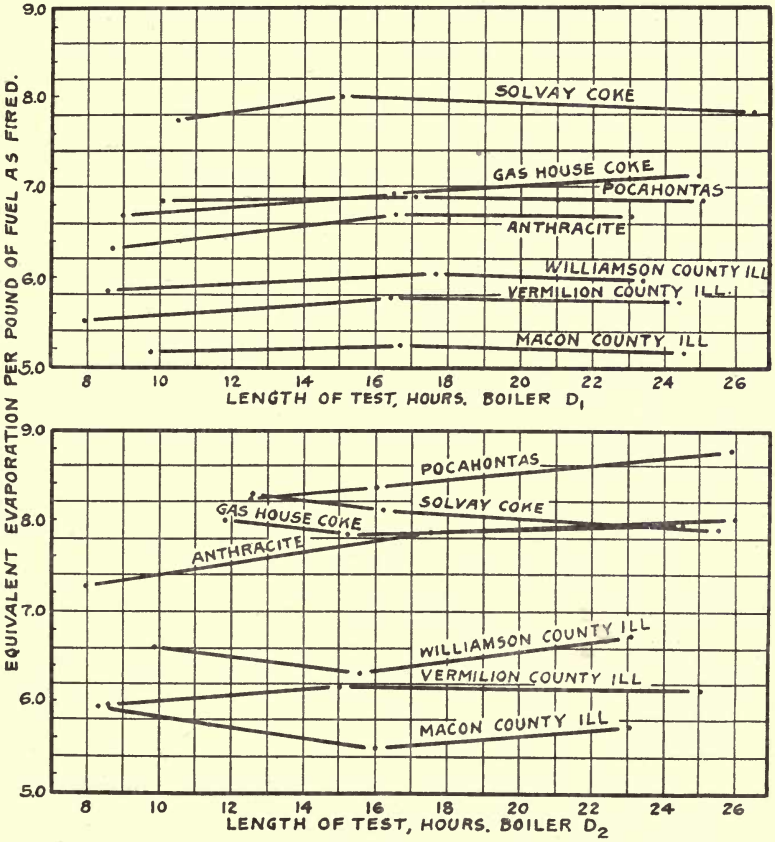

FIG. 6 RELATION BETWEEN LENGTH OF TEST AND EQUIVALENT EVAPORATION PER POUND OF FUEL AS FIRED

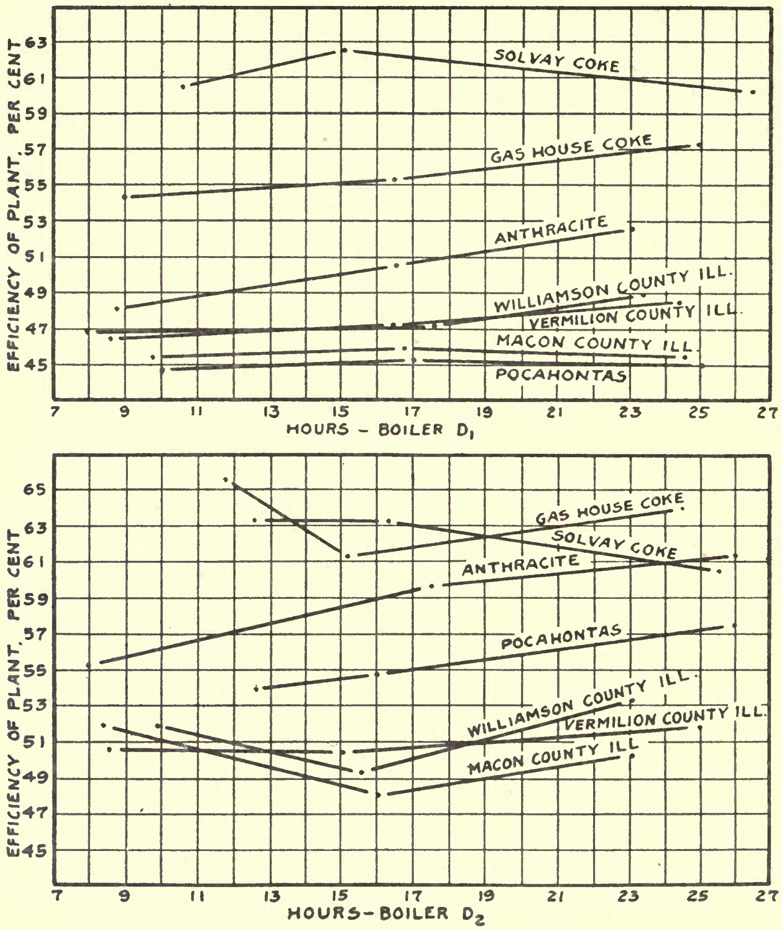

FIG. 7 RELATION BETWEEN PLANT EFFICIENCY AND LENGTH OF TEST

loading and operating at low average capacity, a test of 24 hours or longer will be found desirable.

C. Fuel Cost

(*1*). *Price and heating value.*—The great advantage of Illinois coal for the Illinois user and others within a reasonable distance of the field is in its low price. First-class Illinois coal for domestic purposes can be purchased for one-half or less than one-half the price which must be paid for anthracite. While the heating

TABLE 5

RELATIVE COST OF FUELS

Kind of Fuel	B. t. u. per Pound of Fuel as Fired	Cost of 14600 B. t. u. cents	B. t. u. per 1 cent	Cost of 14600 B. t. u. Based on Anthracite as 100% (per cent)	B. t. u. in per cent Based on Anthracite as 100%	Cost per Ton of 2,000 lbs. in Local Market	Cost in per cent Based on Anthracite as 100%
Anthracite	12682	0.47	30417	100	100	$8.25	100
Pocahontas	14753	0.27	54074	57.4	116.3	5.50	66.6
Gas House Coke	12053	0.30	48667	63.8	95.0	5.00	61.0
Solvay Coke	12505	0.35	41714	74.5	98.6	6.00	72.7
Illinois, Williamson county	12275	0 22	66364	46.8	96.8	3.75	45.5
Illinois, Macon county	11005	0.23	63478	48.9	86.8	3.50	42.4
Illinois, Vermilion county	11546	0.18	81111	38.3	91.0	2.85	34.5

value of the anthracite and other high-priced fuels is in general greater than the Illinois coals, the difference is not so great as to be in any sense commensurate with the difference in price. Table 5 gives information concerning the relative cost of the fuels tested. The heating value of the Pocahontas coal is considerably higher than the other fuels, that of the anthracite somewhat higher than the Illinois coal, while the cokes have approximately the same heating value as the highest given for the Illinois coal. It will be noted that the B. t. u. (British thermal units)per pound of anthracite is 12682 as compared with a value of 12275 for a comparatively high-priced Illinois coal and a value of 11546 for a somewhat cheaper Illinois coal. In one case the Illinois coal costs 45.5 per cent of the price of the anthracite and contains 96.8 per cent of its heating value. In the other case the Illinois coal costs but 34.5 per cent of the price of the anthracite and contains 91 per cent of its heating value. While it is recognized that under present conditions the heat content alone is by no means a sufficient measure of the value of the coal, this great discrepancy in price per heat unit suggests the need of improvement in the methods of burning the cheaper fuel. If all other advantages or disadvantages could be equalized or eliminated, the B. t. u. delivered by the fuel would be the direct measure of its value.

(2). *Relative cost as shown by tests.*—Table 6 presents comparisons relative to fuel costs. The values tabulated in Columns 6 to 13 inclusive are averages for all tests run with each fuel with each boiler. Columns 1 and 2 give the kind and cost of each fuel.

TABLE 6 COMPARISON OF FUEL COSTS

1	2	3	4	5	6	7	8	9	10	11	12	13
Kind of Fuel	Cost of Fuel per Ton of 2,000 lbs.	Calorific Value of B. t. u. per Pound Fuel as Fired	Cost per 14,600 B. t. u.	Cost per Pound of Fixed Carbon	Percent of Builders Rating Developed	Fuel as Fired per sq. ft. of Grate Surface per hour	Equivalent Evaporation from and at 212° F. per hour per sq. ft. of Heating Surface	Cost of Evaporating 1000 lbs. of Water from and at 212° F.	Percent Cost of Evaporating 1000 lbs. of Water from and at 212° F., Based on Cost of Anthracite as 100 Percent	Percent Saving of Cost of Anthracite	Cost of Fuel per 100 sq. ft. of Radiating Surface per hour	Efficiency of Plant [Boiler Furnace and Grate]
	dollars	B. t. u.	cents	cents	per cent	lb.	lb.	cents	per cent	per cent	cents	per cent
BOILER D1												
Anthracite	8.25	12682	0.47	0.53	66.00	5.6	3.63	62.37	100	0	1.87	50.41
Pocahontas	5.50	14753	0.27	0.38	63.88	5.2	3.51	40.04	64.2	35.8	1.20	44.97
Gas House Coke	5.00	12025	0.30	0.31	65.48	5.3	3.60	36.20	58.0	42.0	1.09	55.65
Solvay Coke	6.00	12474	0.35	0.35	64.46	4.7	3.54	38.10	61.1	38.9	1.14	61.12
Illinois, Williamson county	3.75	12266	0.22	0.39	64.04	6.0	3.51	31.09	49.8	50.2	0.93	47.53
Illinois, Macon county	3.50	11005	0.23	0.44	65.54	7.1	3.60	33.71	54.0	46.0	1.01	45.64
Illinois, Vermilion county	2.85	11552	0.18	0.35	65.13	6.2	3.59	25.14	40.3	59.7	0.76	47.51
BOILER D2												
Anthracite	8.25	12682	0.47	0.53	62.33	4.4	2.65	53.54	100	0	1.61	58.71
Pocahontas	5.50	14753	0.27	0.38	64.09	4.1	2.72	32.51	60.7	39.3	0.97	55.43
Gas House Coke	5.00	12076	0.30	0.31	62.48	4.2	2.66	31.50	58.8	41.2	0.95	63.62
Solvay Coke	6.00	12531	0.35	0.35	60.78	4.0	2.58	37.08	69.3	30.7	1.12	62.34
Illinois, Williamson county	3.75	12284	0.22	0.39	64.81	5.3	2.75	28.61	53.4	46.6	0.86	51.51
Illinois, Macon county	3.50	11005	0.23	0.44	65.74	6.2	2.79	30.70	57.3	42.7	0.92	50.06
Illinois, Vermilion county	2.85	11543	0.18	0 35	65.30	5.8	2.77	23.40	43.7	56.3	0.70	50.94

These were purchased mostly from local dealers and have already been described in the paragraph on fuels on page 14. Almost all of these fuels can be purchased somewhat more cheaply in larger quantities. Column 3 gives the heating capacity per pound for each fuel as taken from Table 3, page 18 and Column 4 the cost of 14600 B. t. u. as purchased in each. (The number 14600 B. t. u. as the calorific value of a pound of pure carbon is taken as a convenient unit for comparison.) In Column 5 is given the cost per pound of fixed carbon for the different fuels. Columns 6, 7 and 8 give three of the principal operating conditions inserted here for convenience in making comparisons and in showing the degree of uniformity of these conditions. Columns 9, 10 and 11 give the fuel cost of evaporating 1000 lb. of water from and at 212° F. and percentage relations concerning the same. Column 12 also presents the results relative to fuel cost and evaporation stated in terms of serving 100 sq. ft. of radiation. Column 13 gives averages of plant efficiencies.

(*3*). *Cost per B. t. u. and per pound of fixed carbon.*—It will be noted that the cost per B. t. u. is almost three times as much in the case of anthracite as in the cheapest of the Illinois coals. When comparing the costs per pound of fixed carbon, which under present conditions of burning is a very important consideration, the differences in price are not as marked, the cokes having the lowest cost per pound in this respect. It is to be supposed that the heat content of the fixed carbon is utilized to about the same extent for all the fuels, the variations in efficiency being largely due to incomplete utilization of the heat-content of the volatile matter. The relation of efficiency to fixed carbon content has already been shown graphically in Fig. 1, page 22. In Fig. 8 and 9 average efficiencies have been plotted with relation to cost per B. t. u. per cent volatile and per cent of fixed carbon. These figures show graphically the higher efficiencies obtained with the higher priced fuels, and those high in fixed carbon content, as contrasted with those high in volatile matter, and indicate the desirability of developing methods for burning the cheap and high volatile fuels in a more efficient manner.

(*4*). *Cost of evaporation.*—The rate of combustion and rate of evaporation per square foot of heating surface are both lower in the case of boiler D_2 owing (aside from efficiency differences) to the greater grate and heating surfaces of that boiler relative to the

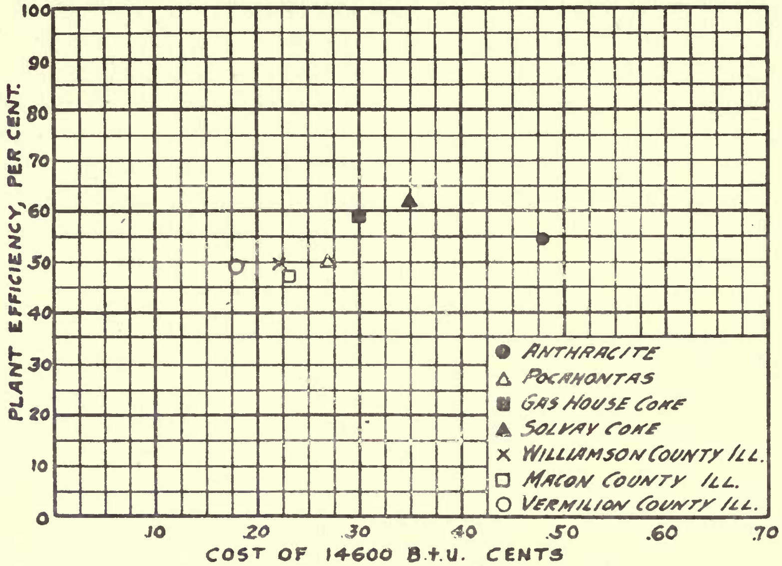

FIG. 8 RELATION BETWEEN PLANT EFFICIENCY AND COST OF 14600 B. T. U.

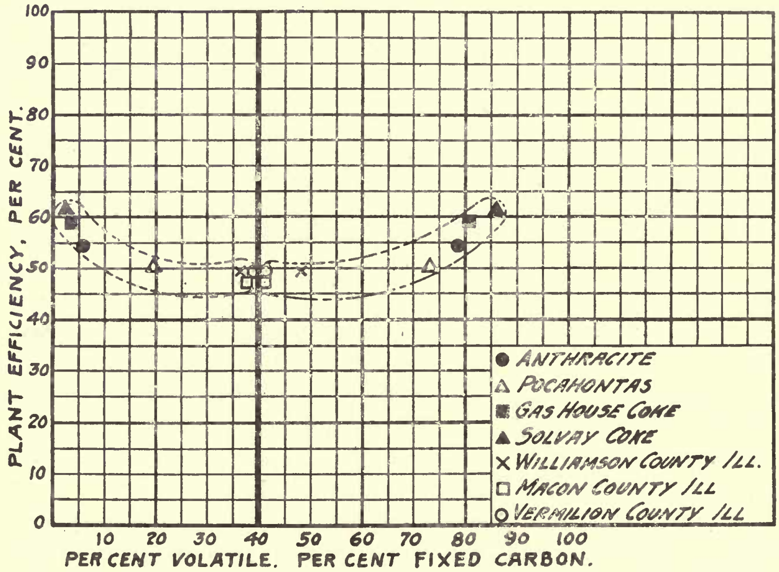

FIG. 9 RELATION OF EFFICIENCY TO PER CENT VOLATILE AND PER CENT FIXED CARBON

rated capacity. The cost of evaporating 1000 lb. of water from and at 212° F. varies from 62.37 cents for anthracite on boiler D_1 to 23.40 cents for the cheapest of the Illinois coal tested on boiler D_2. If evaporative performance alone be considered, this shows a saving of 62.5 per cent of the cost of the anthracite for the extreme cases noted. Considering each boiler separately the corresponding figures are savings of 59.7 and 56.3 per cent, respectively, in the case of boiler D_1 and boiler D_2. Similar differences as between anthracite and the other fuels, also between Illinois coals and the Pocahontas coal and the cokes, while not as great, are sufficient to warrant, other conditions being equal, the choice of Illinois coal on the ground of economy. The same percentage differences relative to fuel cost apply to the cost of serving 100 sq. ft. of radiation per hour as to the cost of evaporating 1000 lb. of water, and Column 12 merely presents in a slightly different manner the fact that as between the extreme cases of the tests considered the same heating effect was produced by one of the Illinois coals at 37.5 per cent of the fuel cost of the anthracite.

(*5*). *Relative fuel values as determined by tests.*—In Table 7 are presented relative values of the fuels tested. These values are based upon evaporative performance as determined under the test conditions and this fact should be borne in mind in comparing them. In the first part of the table the cost of evaporating 1000 lb. of water from and at 212° F. is shown for fuel prices ranging from $1.00 to $10.00 per ton for each fuel. Comparisons may be made in the following manner: if in a certain locality anthracite costs $8.00 per ton and Williamson County, Illinois, coal cost $4.00 per ton it will be seen that it will cost 56.21 cents to evaporate 1000 lb. of water with the anthracite and 31.84 cents to do the same work with the Illinois coal.

In the second part of the table the same relative values are given in a somewhat different manner. The relative values of the different fuels per ton are expressed in dollars with the price of anthracite ranging from $1.00 to $10.00 per ton. If, for example, in a given locality, anthracite costs $8.00 per ton, Williamson County, Illinois, coal is (for evaporating purposes) worth $7.03 per ton and if the Illinois coal can be bought for a less price than $7.03 a saving can be made by using it instead of the anthracite. Again, if at a certain place Williamson County coal can be purchased for $3.51 per ton then (for evaporative

TABLE 7

RELATIVE VALUE OF FUELS FOR USE IN HOUSE-HEATING BOILERS AS DETERMINED BY EVAPORATIVE TESTS ON TWO TYPES OF BOILERS WHEN OPERATED AT 65 PER CENT OF THEIR RATED CAPACITY

Kind of Fuel	Cost in Cents of Evaporating 1000 pounds of Water from and at 212° F., with Price of Fuel Ranging from $1.00 to $10.00 per Ton of 2,000 pounds									
	$1	$2	$3	$4	$5	$6	$7	$8	$9	$10
Anthracite	7.03	14.05	21.08	28.11	35.13	42.16	49.19	56.21	63.24	70.27
Pocahontas	6.59	13.19	19.78	26.37	32.97	39.56	46.15	52.75	59.34	65.93
Gas House Coke	6.77	13.54	20.30	27.07	33.84	40.61	47.37	54.14	60.91	67.67
Solvay Coke	6.27	12.53	18.80	25.07	31.33	37.60	43.87	50.13	56.40	62.67
Illinois, Williamson county	7.96	15.92	23.88	31.84	39.80	47.76	55.72	63.68	71.64	79.60
Illinois, Macon county	9.20	18.40	27.60	36.80	46.00	55.20	64.40	73.60	82.80	92.00
Illinois, Vermilion county	8.52	17.04	25.55	34.07	42.59	51.11	59.63	68.15	76.66	85.18

Kind of Fuel	Relative Value of Fuels (Determined by Evaporative Tests) with Price Varying from $1.00 to $10.00 per Ton of 2,000 pounds of Anthracite									
	$1	$2	$3	$4	$5	$6	$7	$8	$9	$10
Anthracite	$1.00	$2.00	$3.00	$4.00	$5.00	$6.00	$7.00	$8.00	$9.00	$10.00
Pocahontas	1.07	2.14	3.21	4.28	5.35	6.42	7.49	8.56	9.63	10.70
Gas House Coke	1.04	2.07	3.12	4.15	5.19	6.23	7.27	8.31	9.35	10.39
Solvay Coke	1.12	2.23	3.34	4.46	5.58	6.69	7.81	8.92	10.04	11.15
Illinois, Williamson county	.88	1.76	2.64	3.51	4.39	5.27	6.15	7.03	7.91	8.79
Illinois, Macon county	.76	1.52	2.28	3.04	3.80	4.57	5.33	6.09	6.85	7.61
Illinois, Vermilion county	.82	1.64	2.46	3.29	4.11	4.93	5.75	6.57	7.39	8.21

purposes) anthracite is at that place only worth $4.00 per ton and if more than $4.00 must be paid for anthracite the additional amount must be considered as a loss or as being expended for advantages possessed by the anthracite such as cleanliness, and ease of fire control not possessed by the other fuel.

D. Control

Under the conditions of the tests little difficulty as to control or regulation was experienced. The observers were at all times present and gave such attention as was required to maintain the capacity desired. As already explained for these tests, questions relating to attention required, control and cleanliness were considered of secondary importance to obtaining tests comparable upon an evaporative performance basis. When burning the anthracite and the cokes, almost no attention was given the fire from one time of firing to the next. A preliminary adjustment of the chains operating the ash-pit damper and check was made for each fuel if considered necessary and was in general not changed during the tests with that fuel. It was found advisable to keep the ash-pit as nearly air tight as possible except for the damper in the ash-pit door in order that the fire might be effectually checked when the damper was closed. This was found particularly desirable in the case of the quick burning Illinois coal. In general the attention required by the Pocahontas and Illinois coals was considerably more than that required by the anthracite and coke. The regulation was also much more uniform when burning the anthracite and coke than with the other fuels.

E. Smoke

In Table 15, page 90, Appendix A, are given data relative to the smoke produced. Smoke records were not taken at all times. For the majority of the tests a record was taken for only one firing interval, that is, from the time of firing one charge of fuel to the time of making the next charge, and no data are here tabulated except such as extend over such a complete interval. Smoke records taken during the first firing interval were affected by the smoke produced by the kindling used. This is particularly marked in the case of the Solvay coke as practically no smoke was produced with this fuel after the first firing. During the time of making smoke records, observations were made at one minute intervals while smoke was being produced and at somewhat longer intervals when it was known that no smoke was being produced. The smoke produced was often of a yellow or brownish color and difficult to compare by means of the Ringelmann color scale, also owing to several changes in the personnel of observers it is not to be expected that the observations are strictly comparable. It is believed, however, that they represent fairly well the smoke conditions as nearly as that can be done by the methods employed. In making and tabulating the smoke records the Ringlemann chart numbers 1, 2, 3, 4 and 5 were considered as representing 20, 40, 60, 80 and 100 per cent black smoke respectively.

F. Cleanliness

In matters of cleanliness in and about the boiler room, the anthracite and coke were superior to the other fuels. The total ash from the Pocahontas coal was comparatively small in amount, free from clinkers and easily handled. This also was true to a somewhat less extent for the anthracite and cokes, while the ash from the Illinois coals contained more or less clinkers, was obtained in greater amount and was more troublesome to handle. Observations as to the thickness of the soot and ash collecting upon the walls of the flues were made at the end of the tests. These observations were incomplete and varied greatly as compared with each other and are not reported. For a number of the tests the soot which had collected in the flues was burned out during the tests while in other cases this did not happen. Owing to the arrangement of the flue surfaces with respect to the fire-pit this burning of the soot was much more apt to take place in boiler D_1 than in D_2.

G. General

In making fuel tests with house-heating boilers especially if it is desired to consider the boiler as well as the fuel being tested, it would seem advisable to test at approximately the average capacity at which the fuel and equipment are to be operated, or if the load demand is to be very variable, to test under conditions approximately similar to the operating conditions. If the boiler is to be used for heating purposes where the load demand will approach its rated capacity and be fairly constant over a considerable portion of the day, as might be the case in many comparatively large installations, tests under those conditions will give results as to efficiency, rate of evaporation, and other conditions which will be dependable and of value. On the other hand, tests run under conditions similar to those which might exist in a small residence, only requiring a hot fire for a few hours and an average load of possibly 20 per cent or 30 per cent of the rated capacity, would give results for the most part applicable only to like service conditions. This would necessitate tests of at least two general types, one of which would be quite similar to tests as ordinarily run upon power boilers, probably making evaporative performance the main item sought, and the other would be of the nature of a service test where much more relative attention would be paid to details concerning attendance, control, and cleanliness. Further tests which are now in progress with house-heating apparatus under various conditions as to capacity and service will, it is hoped, throw some further light upon the relations existing under widely varying service conditions.

In making a comparison of the fuels tested as to the advantages or disadvantages possessed by each, it is necessary to keep in mind the conditions under which these particular tests were made. Other test conditions as to capacity or attendance might warrant in some respects quite different conclusions.

Several general observations may, however, be made. Considering the cost factor as expressed in the cost per ton of fuel, cost per heat unit and cost per unit of evaporation, the Illinois coal has so great an advantage over anthracite or high-priced eastern coals that it seems probable that this factor alone will in a very large number of cases and to an ever increasing degree bring about the use of the cheaper fuel. This condition will come about in spite of recognized disadvantages with regard to smoke, dirt and more or less troublesome fire control, and emphasizes the necessity of perfecting conditions, fuels, or equipment, so that these drawbacks may be eliminated or reduced to a minimum. Fire conditions and general cleanliness can be bettered through proper screening and sizing of the coal, probably through washing at the mines, and through improvements made upon the fuel burning equipment. Similar care and attention to the matter of details will also to a certain extent reduce the smoke given off. At present, however, it seems unlikely that we can hope to burn Illinois coal under average domestic conditions without producing an amount of smoke which must be both unsightly and injurious. Except for a limited number of localities where effective smoke abatement laws may be operative, these conditions with respect to smoke will doubtless continue to grow worse with the increasing use of this fuel. Sufficiently decided and immediate improvement in regard to smoke prevention when burning Illinois coal in these small units is hardly to be looked for, and the remedy would seem to be rather in central station heating work or in previous preparation of the fuel to render it smokeless. Central station heating is at present only to be considered under special conditions and can not be considered as a solution of the problem as a whole. The most important and at the present time practicable method of previously preparing the fuel is through its conversion into coke. Considering cost as illustrated by the tests made it would appear that coke is still at a considerable disadvantage with respect to the raw Illinois coal, not, however, to so great an extent as anthracite. Coke has the advantages of smokelessness and cleanliness possessed by anthracite, but upon the other hand is handicapped by certain disadvantages, such as its comparative bulk, the non-suitability of a great proportion of the present heating apparatus to burn it to the best advantage, or in sufficient quantity under extreme weather conditions. Apparatus especially designed for burning coke will doubtless eliminate these difficulties to a large extent. Manufacturers of house-heating apparatus are at present offering equipment specially designed to meet this demand. Further, it is to be hoped that with the increased coke production, particularly the increased production from Illinois coal, there will come prices that will permit coke to compete favorably with the less clean fuels with respect to cost. The general use of coke as fuel for domestic purposes, and the consequent non-production of black smoke would eliminate a phase of the smoke problem which at present is both serious and difficult to handle. In a larger way also, the use of coke, as prepared for example by the Solvay or by-product process, appears to be in the direction of a solution of both the smoke problem and the problem of the economic use of the coal supply. Aside from the condition of blackness, due to unconsumed carbon, smoke contains other constituents, also injurious to both health and materials. The sulphur content, which in Illinois coal is relatively high, gives rise to one of the most injurious of such constituents. The proper preparation of Illinois coal for domestic use, whatever the process may be, should take out or reduce the quantity of injurious elements contained in the coal. The process of coal washing and the conversion of coal to coke are both beneficial in this respect and may be considered as steps in the right direction with regard to reducing the injury due both to the visible blackness of the smoke, and to the injurious constituents which occur, such as colorless gases.

In general, then, we may conclude: (1) that on the score of economy the high-priced eastern coals must give way to the cheaper home product; (2) that that product will be used in continually increasing quantities for domestic purposes; (3) that this condition will be accompanied by improved equipment and methods of burning the cheaper fuel; (4) that the use of raw Illinois coal will continue to be accompanied by a considerable amount of smoke and dirt which must eventually lead to some adequate method of preparing this fuel in order to eliminate this feature; (5) that the conversion of Illinois coal to coke offers, at present, a seemingly satisfactory method of such preparation;

and (6) that with the adaptation of equipment to satisfactorily burn coke at a price which for coke will put it on an equal footing with raw coal, coke may be expected to take a very important place as a domestic fuel, and be an important factor in its relation to the smoke problem and the fuel question as a whole.

10. *Equipment*

These tests were conducted with two house-heating boilers installed by the Engineering Experiment Station at the University of Illinois. The boilers have been designated as boiler D_1

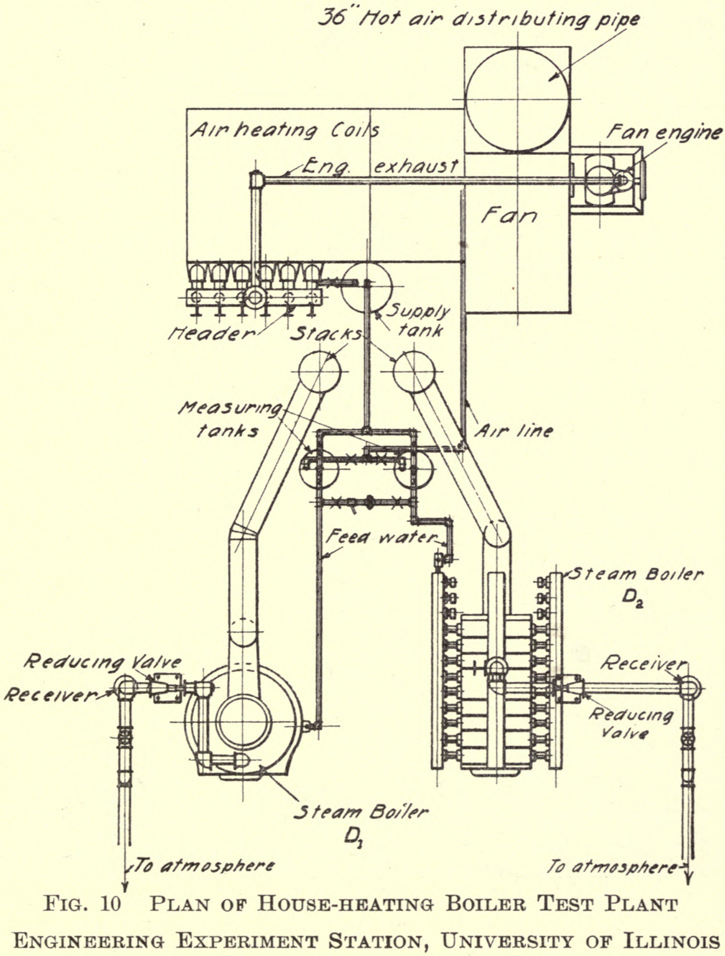

FIG. 10 PLAN OF HOUSE-HEATING BOILER TEST PLANT
ENGINEERING EXPERIMENT STATION, UNIVERSITY OF ILLINOIS

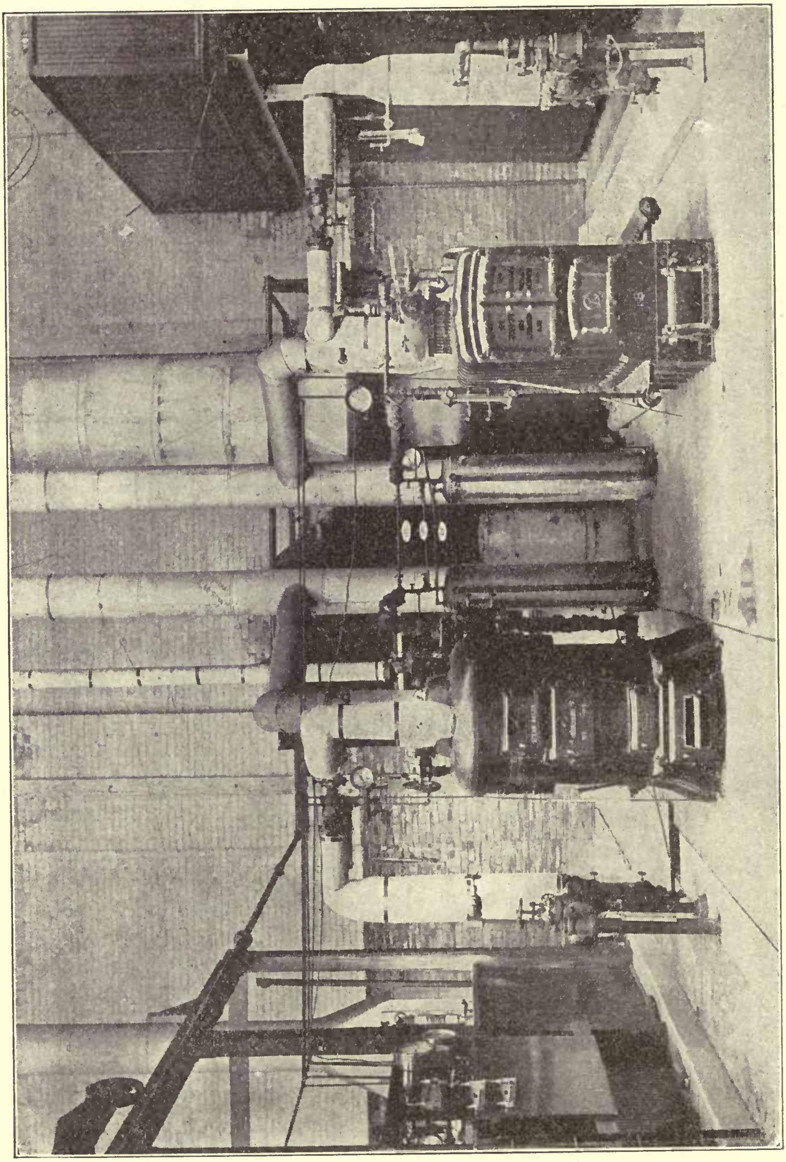

FIG. 11 GENERAL ARRANGEMENT OF PLANT

and boiler D_2. In the U. S. G. S. bulletin, which also reports the principal data and result of these tests, boilers D_1 and D_2 are referred to respectively as boilers A and B.

In Fig. 10 is shown in plan the arrangement of the plant, and in Fig. 11, from a photograph, is shown the general arrangement. The boilers are set independently, each being provided with similar load regulators, return feed water systems, and stacks. The flow is so arranged that the steam may be discharged to the atmosphere through an exhaust head above the roof of the building, or into heating coils at the rear of the boilers. These coils contain 1000 sq. ft. of radiating surface and are arranged in six sections, any number of which may be cut out, changing the amount of radiation in proportion. They form a part of the regular heating system of the laboratory.

Boiler D_1 is made up of four horizontal cast-iron sections, the base and grate section, the fire-pot, an intermediate circulation section, and the dome. Fig. 12 gives a view of the boiler erected. The water space surrounds the fire-pot, and is continued into the intermediate and dome sections through three nipples.

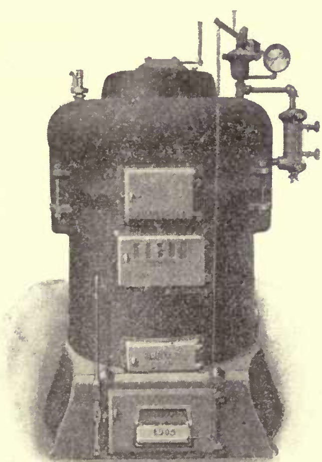

FIG. 12 BOILER D_1

The boiler upon which the tests were made is one rated at 800 sq. ft. The principal dimensions and proportions of this boiler are given in Table 8.

TABLE 8

DIMENSIONS OF BOILER D_1

Rated capacity, radiating surface	square feet	800
Height over all	feet	5½
Floor space	square feet	9
Size of fire door	inches	8½ x 15
Height of fire door above grate	inches	14
Fuel capacity to center of fire door	pounds	290
Kind of grate		plain rocking
Size of grate	inches	28 diameter
Area of grate surface	square feet	4.28
Area of air space	square feet	2.15
Ratio of air space to grate surface	per cent	50
Mean height of furnace	inches	22.5
Height of chimney above grate	feet	39
Sectional area of chimney	square feet	1.07
Area of flue connecting to chimney	square feet	.55
Length of flue connecting to chimney	feet	14
Least flue area in boiler	square feet	.67
Ratio of least flue area to grate surface	per cent	15.5
Smoke outlet above grate	feet	4.17
Kind of draft		natural
Direct water heating surface	square feet	18.8
Indirect water heating surface	square feet	20.7
Superheating surface	square feet	4.2
Total heating surface	square feet	43.7
Ratio of direct heating surface to total	per cent	43
Ratio of total heating surface to grate surface		10.2 to 1
Total water and steam space	cubic feet	7.38
Steam space	cubic feet	3.07
Water space	cubic feet	4.31
Square feet of external boiler surface in contact with water or steam		37.88

Boiler D_2 represents a type of sectional construction in which the base or grate portion and the water-heating portions are built up of interchangeable cast-iron sections, these sections or water legs being connected by means of external circulation drums or headers. Fig. 13 and 14 are respectively an assembled and a sectional view of the boiler, and give an excellent idea of the water space, gas travel, and general construction.

Fig. 13 is from a photograph of the boiler tested.

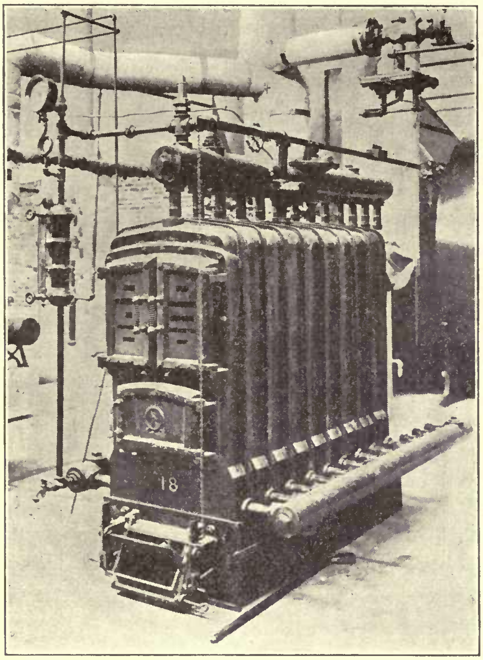

FIG. 13 BOILER D_2

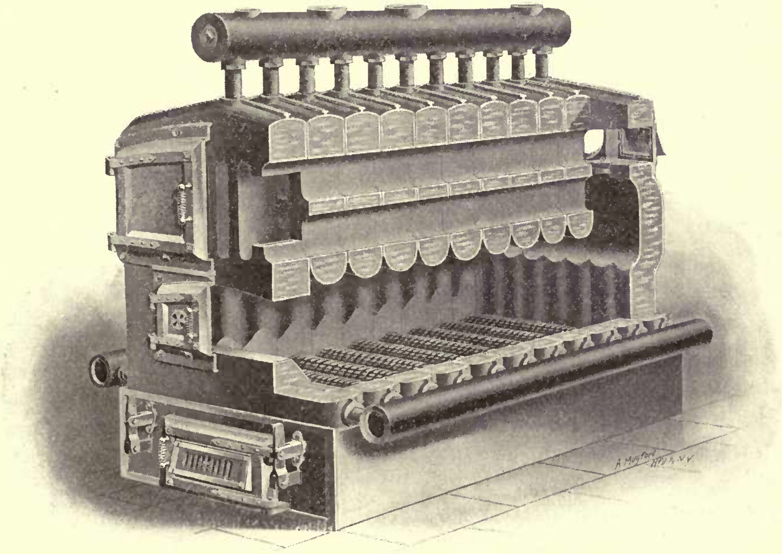

FIG. 14 SECTIONAL VIEW BOILER D_2

This type of boiler is particularly adapted to a number of experimental studies of house-heating boiler work as related to boiler proportions, on account of the ease with which such proportions may be varied. This boiler is manufactured in three widths of grate, and boilers of different capacities are obtained by combining with the different widths of grate a greater or less number of water leg and grate sections.

The boiler installed in the plant has a grate 18 in. wide, is supplied with ten intermediate sections, and with 13-hole supply and return drums, so that a number of combinations are available.

For the tests here considered the boiler consisted of nine sections. The principal dimensions and proportions are given in Table 9.

TABLE 9

DIMENSIONS OF BOILER D_2

Rated capacity, radiating surface	square feet	1075
Height over all	feet	5¾
Floor space	square feet	25
Size of fire door	inches	9 x 15
Height of bottom of fire door above grate	inches	10
Fuel capacity to center of fire door	pounds	370
Kind of grate		patent rocker
Width of grate	inches	18
Length of grate	inches	48
Area of grate surface	square feet	6.0
Area of air space	square feet	3.0
Ratios of air space to grate surface	per cent	50
Mean height of furnace	inches	22
Height of chimney above grate	feet	39
Diameter of flue	inches	14
Sectional area of chimney	square feet	1.07
Area of flue connecting to chimney	square feet	.55
Length of flue connecting to chimney	feet	12½
Least flue area in boiler	square feet	.495
Ratio of least flue area to grate surface	per cent	8.23
Smoke outlet above grate	feet	3.0
Kind of draft		natural
Direct water heating surface	square feet	21.89

Indirect water heating surface	square feet	53.98
Superheating surface		none
Total heating surface	square feet	75.87
Ratio of direct heating surface to total	per cent	28.9
Ratio of total heating surface to grate surface		12.6 to 1
Total water and steam space	cubic feet	11.16
Steam space	cubic feet	3.28
Water space	cubic feet	7.88
Square feet of external boiler surface in contact with water or steam	square feet	103.27

(1) *Feed water system.*—The adoption of the arrangement here described, in which the feed water is forced from the measuring tanks into the boiler by means of compressed air, was influenced to some degree by the desire to use condensation water from the heating coils, noted on page 47. It has, however, proved very satisfactory, requiring little attention, and is convenient, since all of the apparatus is located upon the same level and within easy range for the observer. The arrangement of this apparatus is shown in Fig. 10 and 11, pages 45 and 46. The tanks are ordinary galvanized iron range tanks. One supply tank of fifty-four gallons is connected directly in the return from the heating coils. The inlet pipe passes to the bottom of the tank, and the outlet is at the top so that the tank is at all times filled with hot water.

The measuring tanks, or feed tanks, one for each boiler, 35 gallons capacity, are fitted with gage glasses and scales graduated to read pounds direct, correction being made for varying temperatures. An overflow pipe, with valve, located at the top of the scale, allows filling the tank with a definite charge of water.

These tanks, as stated above, are connected with the laboratory compressed air system, and during feeding are under pressure sufficient to force the water into the boilers. A ½-in. needle valve near the boiler allows close regulation of the feed. The heating system is under three to five pounds pressure, so that the measuring tanks can be filled by simply opening a valve leading to the supply tank. The measuring tanks can be filled somewhat more rapidly if it is desired, by means of compressed air, suitable connections being in place. The air pressure and boiler are cut off from the measuring tanks and the overflow opened during charging.

(2). *Load regulator and separator.*—Since these small heating boilers are designed to regulate themselves, under control of their automatic damper regulators, the rate of combustion may be kept fairly regular by keeping the rate of evaporation constant. This has been accomplished by the use of a pressure regulator, by means of which a steady flow of steam is discharged from a constant pressure receiver through a suitable orifice into the atmosphere, provision being made for varying the load to suit the specific demand of the test.

The receivers perform the duty of separators and are thus used to replace the usual steam calorimeter, for which reason the receivers and pipes are heavily lagged with hair felt and pipe covering, one inch of felt being first laid next to the iron and above this a one-inch thickness of magnesia pipe covering. The regulators are shown to the right and left of the boilers in Fig. 11, page 46.

Fig. 15 shows one of the load regulators with its covering removed. The steam from the boiler passes through the pressure regulator *A* into a 3-inch pipe, which extends through the top of the receiver and nearly to the reducing tee at the bottom. Here the direction of steam is changed and entrained moisture separated, the dry steam passing up and out through *F* and to the exhaust main *J*, through an orifice plate in the 2-inch union *G*, the pipe *J* being open to the atmosphere. Difference of pressure as between the receiver and on the exhaust side of the orifice plate as at *J*, is indicated by a mercury manometer at *C* made up with suitable connections. A slight back pressure due to friction usually existed in pipe *J*. No attempt was made to compute the evaporation in this manner. The moisture separated from the steam collects in the 3-inch trap *D*, the amount of which is indicated in pounds and fractions on the gage glass. Some moisture originally in the steam is, doubtless, evaporated in passing the reducing valve, consequently correction of computed results for quality of steam and conversion to equivalent evaporation from and at 212° are made on the basis of the mean pressure maintained in the receiver, which is usually about two pounds.

Variation in load is obtained by the introduction of suitable orifices at *G*. The by-pass valve *E*, allows changes to be made during operation, the orifices taking the place of a gasket in the union.

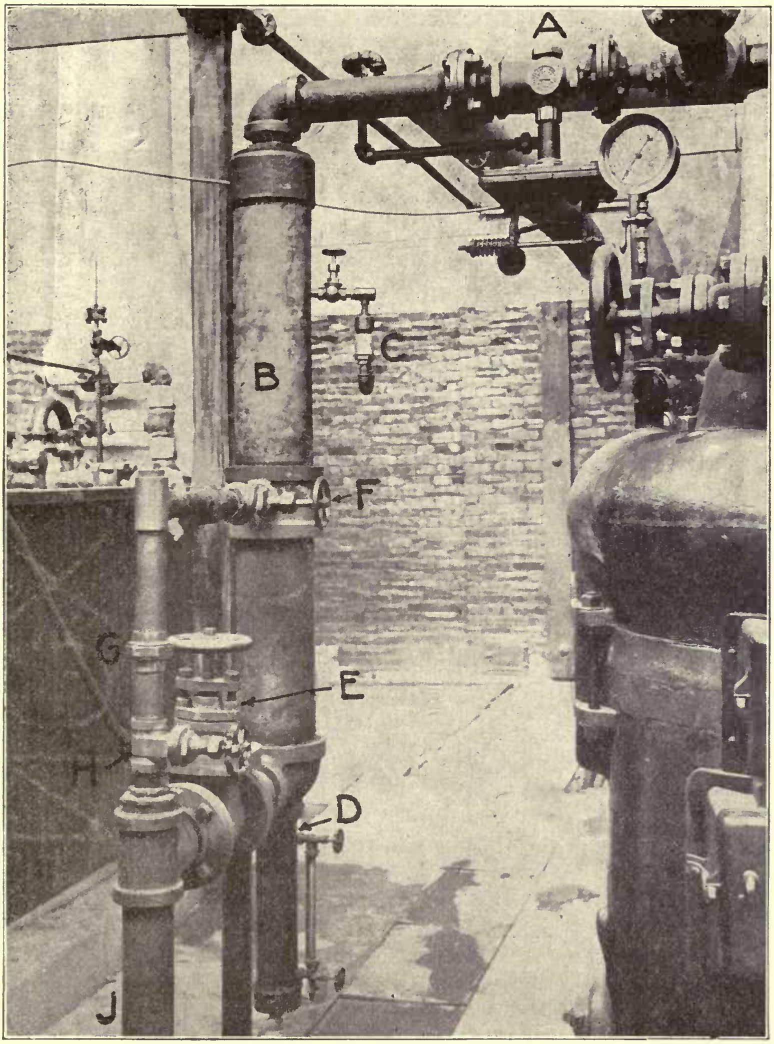

Fig. 15 Load Regulator

II. Fuel Tests with House heating Boilers made by the United States Geological Survey
(58 tests: 47 with briquetted fuel; 11 with raw fuel).

11. *Introduction*

As has been stated already the material presented in Part II was almost entirely supplied through the courtesy of the Technologic Branch of the U. S. G. S. These tests are more fully reported in bulletin No. 366 by the U. S. G. S.

Beginning in October, 1906, a number of evaporative tests were made at St. Louis, Missouri, under the direction of the United States Geological Survey, on the house-heating boiler installed to heat the buildings occupied by the Structural Materials Testing Division. 58 such tests were made; 11 tests were made with raw coal and 47 with briquetted coal having a binder of pitch.

12. *Summary and Conclusions*

The briquets and coal burned on the tests at St. Louis came from eleven states or territories. There were 58 tests, 11 on raw coals, 34 on round briquets and 13 on square briquets. Most tests ran about 8 hours and carried an average steam pressure of from 2 to 3 lb. The amount of fuel fired at each firing varied from 55 to 175 lb. The interval between firings varied considerably; on some tests coal was fired every half hour and on others every two hours. The average efficiency of all of the tests was 51.48; it varied from 38.67 on an Illinois coal to 65.36 on a Virginia coal. The average per cent of builders' rated capacity developed was 59.2. It ranged from 44 per cent on an Illinois coal to 77.2 on an Indian Territory coal. The lowest boiler horse-power developed was 12.1 and the highest 20.6. With fuel at $1.00 per 2000 lb., the cost of evaporating 1000 lb. of water from and at 212° F. varied from 5.56 cents for a Pennsylvania coal briquetted to 11.93 cents for an Illinois coal briquetted.

Most of the briquets, whether made from eastern or western coal, smoked badly for several minutes after firing. Of the coal tested raw, 6 were on western and 5 on eastern coal. The high volatile western coals smoked badly, but the eastern coals made comparatively little smoke.

13. *Fuel*

Table 10 gives a description of the coal and binders used in the briquets tested. Further information relative to the coal tested and to the binders employed has been published in the bulletins of the U. S. G. S.* The chemical properties of these fuels as shown by proximate and ultimate analyses are contained in Table 16, on page 94, Appendix B.

On comparing the results of tests on the coal and briquets there seems to be no advantage in the briquets over coal of a suitable size for house boiler heating. Briquetting a good bituminous coal would be justified when slack is used for material and the gain would be due almost entirely to the more favorable size of the fuel. This gain is less for coals which coke readily than for non-coking coals which are not suitable for domestic purposes in the form of slack. Briquets made from such coal burn fairly well, as they allow the air to pass up through the fuel bed.

These experiments have shown that the pitch binders used are not suitable for a furnace working at the low temperatures common in a house-heating boiler, as they volatilized and in most cases escaped unburned or were deposited on the surface of the boiler. This coating generally burned off once or twice a day, causing a high temperature in the flue, and, as a consequence, danger from fire.

14. *Methods of Conducting Tests*

The tests were made to conform as nearly as possible to actual running conditions of the average house-heating boiler plant. Steam was supplied to two buildings for heating and consequently the load varied with the weather, according to both the temperature of the outside air and velocity of the wind. On only a few of the tests was the heating load so light that steam was turned into the atmosphere.

The tests usually covered a period of about eight hours; during this time the operator tried to maintain a steam pressure of about three pounds. The alternate method, as prescribed by the A. S. M. E. code for making boiler trials, was used in starting and stopping the tests. The boiler was installed in so small a

* Bulletin 332, Report U. S. Fuel Testing Plant 1906-7.
Bulletin 261, Preliminary Report on Coal Testing Plant.
Bulletin 343, Binders for coal briquets.

TABLE 10 COAL AND BINDERS USED IN BRIQUETS

Coal			Shape of Briquet	Binder *a*			
Field Designation	Locality	County		Percentage Used	Flowing Point	Oils by Distillation up to 743° F.	Extraction analysis: Pitch extracted (sample as received) by CS_2
					° *F.*	*Per ct.*	*Per cent*
Arkansas No. 13	Denning	Franklin	Round	7	140.0	34.44	95.20
Illinois:							
No. 7 E	Near Collinsville	Madison	"	8	143.6	25.76	96.90
No. 9 C	Near Staunton	Macoupin	"	9	143.6	25.76	96.90
No. 12 B W	Bush	Williamson	Square	6.25	143.6	39.05	99.66
No. 29 A W	Livingston	Madison	Round	7	143.6	39.05	99.66
No. 29 B	"	"	"	7	143.6	39.05	99.66
No. 30 W	Shiloh	St. Clair	"	8.5	143.6	25.76	96.90
No. 31	Warden	"	"	8	143.6	25.76	96.90
No. 31	"	"	Square	7	161.6	28.98	89.31
No. 33	Trenton	Clinton	Round	8	143.6	25.76	96.90
Indiana:							
No. 1 B	Mildred	Sullivan	"	8.5	161.6	28.98	89.31
No. 5 B	Hymera	"	"	9	143.6	25.76	96.90
No. 6 B	"	"	"	8.5	143.6	25.76	96.90
No. 6 B	"	"	Square	7	143.6	25.76	96.90
Indian Territory:							
No. 2 B	Hartshorne	....	Round	8	186.8	24.70	85.57
No. 2 B	"	....	Square	8	172.4	20.00	99.60
Kansas:							
No. 2 B	Yale	Crawford	Round	7	143.6	39.05	99.66
No. 2 B	"	"	Square	7	143.6	39.05	99.66
Maryland No. 2	Frostburg	Allegheny	Round	8	143.6	25.76	96.90
Missouri No. 10	Bevier	Macon	"	8	143.6	39.05	99.66
Pennsylvania:							
No. 18	Lloydell	Cambria	"	8	143.6	25.76	96.90
No. 18	"	"	Square	7 *b*8	143.6 114.8	25.76 5.76	96.90 100.00
No. 19	Herminie	Westmoreland	Round	8	143.6	25.76	96.90
No. 20	Near Seward	"	Square	6	161.6	28.98	89.31
No. 20 W	"	"	Round	8	161.6	28.98	89.31
No. 22	Huff	"	"	7	161.6	28.98	89.31
No. 22	"	"	Square	6	161.6	28.98	89.31
Pennsylvania No. 15 (one-fourth).	Wehrum	Indiana	Round	6.25	143.6	39.05	99.66
Rhode Island No. 1 (three-fourths).	Cranston	Providence					
Pennsylvania No. 18 (one-fourth).	Lloydell	Cambria	"	8	143.6	25.76	96.90
Miscellaneous No. 9 (three-fourths).	....	....					
Pennsylvania No. 18 (one-half).	Lloydell	Cambria	"	8	156.2	25.47	90.56
Rhode Island No. 1 (one-half).	Cranston	Providence					
Pennsylvania No. 18 (three-fourths).	Lloydell	Cambria	"	8	143.6	25.76	96.90
Miscellaneous No. 9 (one-fourth).	....	....					
Pennsylvania No. 18 (one-half).	Lloydell	Cambria	"	8	143.6	25.76	96.90
Miscellaneous No. 9 (one-half).	....	....					
Virginia No. 5 B	10 miles west of Blacksburg	Montgomery	"	7	143.6	39.05	99.66

a Water-gas pitch except where otherwise noted. *b* Wax tailings.

room that the standard method of starting and stopping the tests was not practicable.

Each test was started with a fire about 4 in. thick. This thickness was gradually increased, varying from 12 to 18 in. depending upon the kind of coal burned and upon the judgment of the operator as to the best thickness for good combustion. To start a test with a 4-in. fuel bed required that the same coal used on the test must be fired for about four hours before the start of the test. To build up the fire required light firings at first and the same procedure was followed to burn it down for a close. At other times during the tests the amount of coal fired was considerably greater. Coal was fired whenever the heat requirements demanded it, usually at a time when the fire had burned down and the steam pressure had dropped. When the coal was fired it was spread over the entire fuel bed. The fire seldom required any attention and it was never poked unless a coal was being burned that coked badly. On the tests the fire was cleaned only just before starting and stopping, except in two or three cases when there was an unusually large accumulation of clinker upon the grate.

Readings were taken of draft, temperature and steam pressure, every 30 minutes. Smoke readings were taken as soon after coal was fired as other observations would permit and it was observed at intervals until the volatile matter had been driven off and no smoke was given off from the stack.

Owing to the many duties of the observer there was difficulty in securing and analyzing representative samples of flue gas, but the results are considered of sufficient accuracy to indicate certain general relations between the air supply and the performance of the boiler.

All gas samples analyzed gave some CO in the flue gas. This was to be expected as the combustion was never complete on any of the tests as evidenced by watching the top of the stack.

Observations showed the smoke black at times of firing and comparable with the Ringelmann charts, gradually turning gray after several minutes. This is of interest owing to the fact that the gases resulting from the combustion of briquets at the Illinois Engineering Experiment Station were usually of a dirty yellowish color and not comparable with the usual standard.

All briquets were fired whole. Shortly after they were fired distillation of the tar took place and condensed on the boiler surface, forming a covering over the flue passages. When the fire was allowed to burn freely the coating on flues ignited. This often happened two or three times during an eight hour run and would increase the temperature in the flues as high as 1500°F. On this account a thermo-couple was used to take the temperature of the stack gases.

The furnace door was opened only at times of firing. An attempt was made on a few special briquet tests to reduce the smoke after firings by opening the slide draft in the furnace door, but either there was not enough air or it was admitted at the wrong point for there was no appreciable reduction of smoke. No attempt was ever made to introduce air over the fire on the regular series of tests.

The flue passages were not brushed during the tests with briquets as the burning of the tar effectually cleaned the boiler surfaces. In some cases the tar coating without doubt greatly lowered the efficiency of the boiler. It will be noted that the raw coal gave better results than when briquetted.

The analyses of the fuel burned and of the refuse were made at the chemical laboratory of the fuel testing plant.

15. *Data and Results*

In Table 16, pages 92 to 98, Appendix B, will be found the principal data and results relative to these tests. Table 17, page 99, gives the average per cent of CO_2, O_2 and CO for 52 of the tests.

16. *Equipment*

Fig. 16 and 17, pages 59 and 60 show plan and elevation drawings of the house-heating boiler plant as tested at St. Louis.

The boiler on which these tests were made is of the sectional type. It contains seven separate sections, measures 66 in. in length, has a grate 36 x 54⅛ in., three 5-in. steam outlets at the top of the sections and is rated to take care of 3150 sq. ft. of radiating surface.

The boiler furnished steam to two buildings, supplying the necessary amount through two of the three outlets. The front outlet was not in use and was capped over. This boiler is made so that feed water may be supplied to every other section. It enters at the base of the section on both sides just above the grate level. There are six return inlets, but in this installation

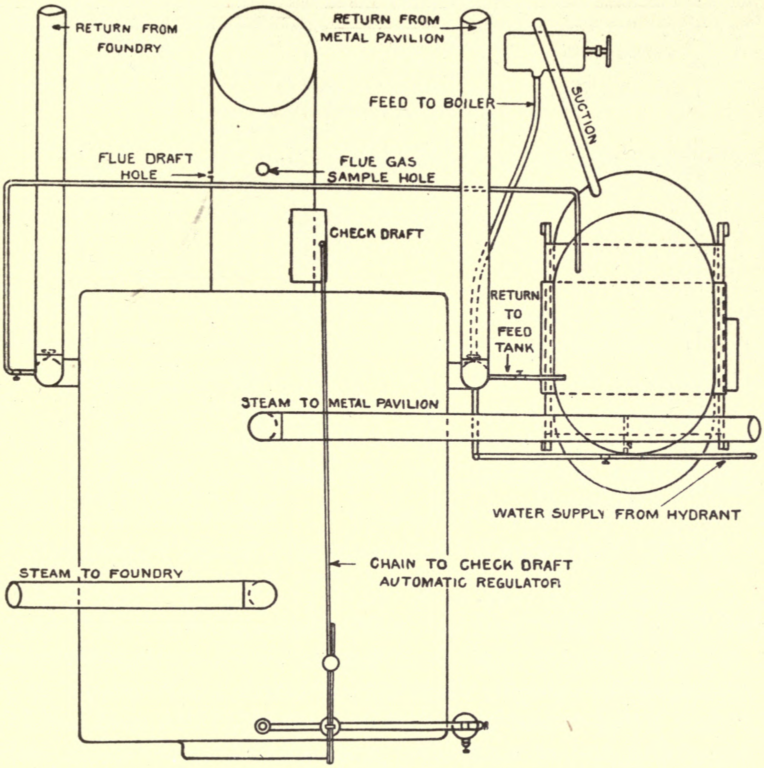

FIG. 16 PLAN OF HOUSE-HEATING BOILER PLANT AT ST. LOUIS, MO.

only the rear two were used. The piping was so arranged that during a test period all of the condensation was returned to a weighing tank, then allowed to discharge into a supply tank from which it was forced into the boiler by means of a hand pump. The temperature of the water entering the boiler varied from 100° to 150° F., but usually averaged 140° F. During a test all the water entered the boiler through one of the rear inlet openings.

A sectional boiler is usually installed so that the steam as it is taken from the sections is first drawn into a collecting drum, so that water will not be carried into the pipes with the steam in case of a sudden demand for steam. There was not enough head room for the installation of this drum at the St. Louis plant and the steam was drawn directly from two sections. Drain pipes con-

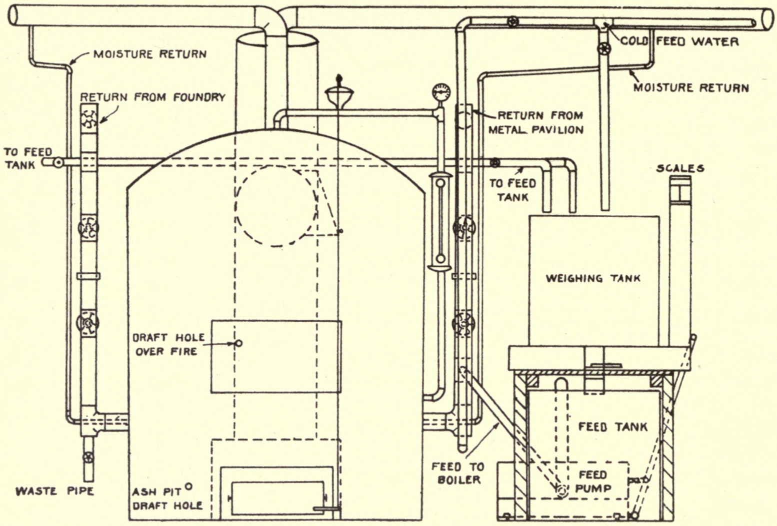

FIG. 17 ELEVATION OF HOUSE-HEATING BOILER PLANT AT ST. LOUIS, MO.

nected with the bottom of the steam pipes, as shown in the drawing, carried moisture back to the boiler. No moisture readings were made on the steam; therefore, in making calculations on the amount of water evaporated, the moisture was not accounted for and the boiler has been credited with slightly more work than it performed.

A siphon damper regulator was used to control the draft through the fire so that a nearly constant steam pressure might be carried. This regulator was connected direct to the lower check also by an arrangement of pulleys to the check in the flue.

On the first 30 tests the draft was supplied by a stack 32.4 ft. above the grate. On these tests both natural and induced draft were used. On the last 28 tests the stack was raised to 44.8 ft. above the grate level. This height of stack always furnished the required amount of draft.

All except the front of the boiler was lagged with about an inch covering of plastic asbestos.

III. Fuel Tests with House-heating Boilers made by the Engineering Experiment Station
(24 tests with briquetted fuel)

17. *Introduction*

24 tests were made when burning briquetted fuel in connection with house-heating boilers by the Engineering Experiment Station of the University of Illinois during the months of June and July, 1907. The tests described in Part II of this article made by the U. S. G.S., at St. Louis, led to the desire to conduct additional tests under more constant conditions than could be maintained at the St. Louis plant.

18. *Summary*

An average capacity of 65 per cent was carried on all of the 24 tests, the variation being from 53.2 to 71.4 per cent. The boiler horse-power developed on boiler D_1 ranged from 4.52 to 4.96; on boiler D_2 from 4.97 to 6.16. The average efficiency of the boiler and furnace, figured on a dry coal basis, gave 44.85 per cent for the 24 tests. Comparing 8 tests on briquets, 4 of which were made on large briquets and 4 on small briquets, it is shown that in every case the large briquets gave an appreciably higher efficiency showing that the size of the coal burned is an important factor. With fuel at $1.00 per 2000 lb., the cost of evaporating 1000 lb. of water from and at 212° F., varied from 6.74 cents on a Pennsylvania briquet test to 12.47 cents on an Illinois test.

The briquets started readily from a wood fire and burned well, but owing to the difficulty of obtaining complete combustion, the average efficiency from an 8 hour test was low. The formation of soot in the flues of boiler D_2 was more troublesome than in boiler D_1. In two instances the flues of boiler D_2 were completely stopped up after an 8-hour run.

To carry only 65 per cent of the rated radiating surface the draft through the fire was either cut off or very nearly so for one-half to three-quarters of the time.

19. *Fuel*

A carload of briquets was shipped to the Engineering Experiment Station at Urbana, Illinois, and the results here recorded are from tests made with this fuel. The briquets were manufactured at the U. S. G. S. fuel testing plant and were of two sizes and shapes. The round briquets were $3\frac{1}{8}$ in. in diameter and 2 in. thick. The square briquets were $4\frac{1}{4}$ in. x $6\frac{3}{4}$ in. x $2\frac{1}{2}$ in. 24 tests were made, twelve on each of two boilers. 18 of the tests were on round briquets manufactured with the Renfrow briquetting machine, the other six with square briquets made on the English briquetting machine. These machines and their products have been described in the bulletins issued by the U. S. G. S., concerning the fuel testing plant at St. Louis.* The square briquets were broken in halves before firing. The percentages of pitch in the briquets varied from 7 per cent to 8 per cent. The chemical properties of these fuels as to moisture and ash are given in Table 18, page 104, Appendix C.

20. *Methods of Conducting Tests*

The methods employed in conducting the tests were also in general the same as those used in making the tests considered in Part I and have been described in connection with those tests under the heading "Methods of Conducting Tests" upon pages 15 to 20 inclusive. For the tests here considered the following are the principal conditions under which they were planned to be run.

(*1*). The load to be maintained between 60 and 70 per cent of the builders' rated capacity.

(*2*). The load to be uniform throughout the test.

(*3*). A steam pressure of 2 lb. to be carried on the heating system.

(*4*). A definite charge of coal to be supplied at each firing.

(*5*). Each test to be of approximately 8 hours' duration.

The air supply was taken entirely through the ash-pit door. On some of the tests it might have been advisable to continuously admit a part of the air used for combustion over the fire through the furnace door or it might have been possible to have increased the over-all efficiency of the boiler by admitting air

*Professional Paper No. 48, Part III.
Bulletin 261. Preliminary Report on Coal Testing Plant.
Bulletin 290. Operations of Fuel Testing Plant in 1905.
Bulletin 332. Report U. S. Fuel Testing Plant, 1906-7.
Bulletin 343. Binders for Coal Briquets.

over the fire for a few minutes after each firing by cracking the furnace door; however, since this is not commercially practicable, no attempt was made to prove or disprove the statement.

The boiler flues were blown after the close of every test, so that the heat developed on each of the tests had an equal chance on the heating surface at the start of the test; however, on some of the trials more soot was formed than on others, which made the heating surface on these trials much less effective at the close of the test than at the start.

The standard method of the A. S. M. E. code for conducting boiler trials was employed, the test being started when the wood was lighted. As soon as the wood was burning well, about 25 lb. of the fuel was fired. In about 8 or 10 minutes, the remainder of a 75-lb. charge of fuel was fired.

Observations concerning temperatures, pressures, drafts and water measurements were recorded every 15 minutes.

As the duration of the trials was to be approximately 8 hours, just enough coal was put on the fire at the last firing to keep up 5 pounds steam pressure until time to close the test.

21. *Data and Results*

In Table 18, pages 102 to 108, Appendix C, will be found the principal data and results relative to these tests.

(*1*). *Soot*—Table 11, below, shows the amount and character of soot found on flues of boilers D1 and D2 as determined and recorded at the end of test. Measurements were taken in the flues of the boiler.

TABLE 11

AMOUNT AND CHARACTER OF SOOT FORMED IN FLUES

Test No.	Boiler	Soot Measurements	Test No.	Boiler	Soot Measurements
136	D1		140	D1	Heavy; ⅛ inch thick
137	D2		141	D2	Heavy; ⅛ inch to ¼ inch thick.
152	D1	Heavy: 1-16 inch to ⅛ inch thick	146	D1	Heavy: large amount.
153	D2	Heavy; 1-16 inch to ⅛ inch thick.	147	D2	Large amount; choked draft
154	D1	Light and fluffy; ⅛ inch thick.			entirely off.
155	D2	Light and fluffy; ¾ inch thick.	148	D1	1-16 inch to ⅛ inch thick.
		Choked draft entirely off.	149	D2	Heavy; large amount.
142	D1	Heavy.	138	D1	Very little.
143	D2	Heavy.	139	D2	Very little.
144	D1	Heavy.	156	D1	Fine and heavy; small amount.
145	D2	Heavy.	157	D2	Very little.
158	D1	Very little.	150	D1	1-16 inch thick or less.
159	D2	Flaky; ¼ inch thick.	151	D2	1-16 inch thick or less.

Owing to the fact that the character of the soot was so variable, it is difficult to draw any conclusion on comparative thickness of soot. The above table shows that there was a big variation in the amount of soot formed. It is noticeable that on several of the tests a great deal of soot lodged in the flues and in a few instances the flues were filled, choking the draft off entirely. More difficulty was experienced with soot on Boiler D_2 than on D_1.

(2). *Smoke*—The smoke observations for the tests made at the Illinois Engineering Experiment Station are not reported owing to the uncertainty of comparative accuracy. The readings were extremely difficult to estimate, due largely to the peculiar color of the smoke. Smoke of about a shade between Ringelmann No. 1 and No. 2, from briquets made with pitch binder, is of a dirty yellowish color and far more offensive than No. 4 smoke from raw or washed coal, and probably would be of about the same gravimetric density as the No. 4 smoke from coal. On all briquet tests, the stack smoked badly for three-quarters of an hour after firing. After about one hour after firing the stack was almost clean, remaining so until another charge was fired.

22. *Equipment*

The equipment used in making these tests consisted of the two house-heating boilers installed by the Engineering Experiment Station of the University of Illinois and designated as boiler D_1 and boiler D_2. Except for a few minor changes in regard to the type or arrangement of the apparatus used in making observations, the equipment and its arrangement are the same as employed when making the 48 tests considered in Part I of this bulletin. Description of this equipment has already been given and will be found upon pages 45 to 53, inclusive.

APPENDIX A

APPENDIX A

23. *Tabulated Results*

The principal data and calculated results of the 48 tests are given in Table 12, on pages 70 to 83. The column heading numbers ranging from 1 upon page 70 to 73 upon page 82, correspond to the item numbers upon a final report sheet which was worked up for each test, and in general are arranged in much the same order as corresponding items in the A. S. M. E code for boiler trials.

The first three columns upon each page of Table 12 are the same, and serve as a guide in showing the connection throughout the different pages. These columns give the laboratory test number, the boiler operated and the kind of fuel used.

Upon page 70 are given the date upon which the test was made, the length of the test in hours, and average values of steam pressures, drafts and temperatures. The average steam pressures are in no case recorded closer than to the nearest half pound. The manometer on the receiver, being connected to give the difference in pressure between the two sides of the orifice, did not indicate the true pressure in the receiver. The pressure on the exhaust side of the orifice plate was, however, so small as not to make the average pressure higher than 2 lb. as recorded above. It will be noted that in one test the average pressure in the receiver was 1.5 lb.

The draft in the ashpit was taken along with other observations at regular 20 minute intervals. Owing to the fact that at the time of taking such observations the damper to the ash-pit might be in any position from tightly closed to wide open, an average of such readings would be of little or no value and has been omitted from the tabulated results. In general the draft in the ash-pit varied from practically zero when the ash door opening was wide open, to approximately the same draft as existed over the fire when the damper was closed. A record of the position of the ash door damper and the smoke pipe check was kept in connection with the observations made upon drafts.

Pages 72 and 75 contain information relative to the fuel. Items 20, 21 and 21.1 show the amount of moist fuel fired while item 21.2 shows the same as corrected on account of the residual fuel drawn at the end of the test. Items 23 and 23.1 show the amount of fuel expressed as dry or moisture-free fuel. Item 23.2 gives the amount of dry fuel actually consumed, further correction having been made allowing for the unburned fuel removed with the ash. Items 24 and 25 exhibit respectively the ash and residual fuel which were obtained for each test. Items 37 and 38, page 76 give the analyses of the residual fuel as divided into carbon and earthy matter, while items 40 and 41 give corresponding information relative to the ash. Items 45 and 46 give the calorific value for the fuel used in each test expressed upon both a dry fuel and upon a fuel as fired basis. Items 43 and 44 exhibit the average rate of combustion maintained, expressed as dry fuel per hour and as dry fuel per square foot of grate surface per hour.

Upon page 74 are given the proximate analyses of the fuel for each test with the items expressed in per cent of fuel as fired and moisture-free coal. This table has already been referred to in the sections concerning fuel and methods.

Page 78 presents information relative to the water evaporated. Item 47 gives the moisture in the steam as determined in the receiver. The steam from the boiler to the receiver was probably dried to a considerable extent in passing the reducing valve and a part of the moisture collected in the receiver is due to condensation rather than entrained moisture. The moisture as here recorded is not a measure of the dryness of the steam as generated by the boiler at boiler pressure. It has, however, been used in the calculations for determining boiler performance as the moisture in the steam when reduced to receiver pressure. It will be noted that the moisture content so determined is comparatively small and the corresponding corrections of little effect in the final determinations regarding evaporative performance. Items 49, 50 and 52 give the amount of water fed to the boiler, the same corrected for quality of steam to give the amount evaporated and the equivalent evaporation from and at 212° F. Items 53 and 54 give operating conditions with reference to water evaporated, showing the total equivalent evaporation per hour and the same per square foot of heating-surface per hour. Items 48 and 51 are factors used in calculating other items listed on the table.

Upon page 80 are given results relative to the load carried. As already stated, the attempt was made to run at a load equal to approximately 65 per cent of the boiler rating. An examination of the per cent given under item 56 shows that the highest capacity recorded for any test was 71.25 per cent and the lowest 58.33 per cent, the remainder of the values ranging between these two. Item 55 gives the load expressed in square feet of radiation served. For the purpose of calculating this load an evaporation of 0.3 lb. of water from and at 212° F. was considered equivalent to serving one square foot of radiation for one hour. Table 8 shows that of the external boiler surface of boiler D_1, 37.88 sq.ft. was on the inner side in contact with steam and water, and Table 9 shows that 103 27 sq. ft. of the surface of boiler D_2 was under similar conditions. This surface could be considered radiating surface and if added to the surface served as shown by item 55 would increase the load and show the boiler operating at a somewhat higher capacity than is shown by item 56, which is based upon evaporation only, without regard to radiation loss from the boiler. Item 55.1 shows the load carried when this boiler radiating surface is added to the load as calculated from evaporative performance. It is inserted here in order to call attention to the very considerable difference which such an assumption would make, but is not otherwise used in any of the calculations involving capacity, item 55 being used for that purpose. It was not considered advisable to make use of item 55.1 owing to the uncertainty as to how closely a square foot of the boiler radiating surface might be considered equivalent to a square foot of radiation as defined above, and especially on account of the fact that house-heating boilers in service may not be lagged and their exposed surface is rarely considered in estimating the radiating surface served. In case the boilers under consideration were lagged a portion only of the heat lost by radiation could have been utilized in evaporating water.

Items 57 and 58 give the equivalent evaporation per pound of fuel. Items 59 and 60 give the fuel consumed per hour per 100 sq. ft. of radiation, expressed in fuel as fired and in dry fuel.

Items 61 and 62, page 82, give efficiencies as calculated in the usual manner. Item 61 gives the efficiency when only the boiler and furnace are considered. Item 62 gives the plant efficiency, that is, the efficiency of the boiler, furnace and grate. The same grates were used thoughout and the efficiency of boiler and furnace without grate differs from the efficiency with grate only on account of the unconsumed fuel which passed through the grate. The grates may have been more suitable for the retention of some of the fuels than of others. In so far as the grate serves as a part of the furnace, as in the matter of air supply, its effect is of course included in both efficiencies.

Items 64 and 65 give the cost of serving 100 sq. ft. of radiation and of evaporating 1000 lb. of water from and at 212° F. based upon an assumed fuel cost of $1.00 per ton of 2000 lb.

Items 70, 71, 72 and 73 give a number of the conditions which prevailed with respect to fire conditions. Item 70 (fuel fired at each firing) shows that 75 and 105 lb. of fuel constituted the firing charge for boilers D_1 and D_2, respectively. The first fire of each test, however, consisted of this amount of fuel and a sufficient weight of white pine kindling to ignite it. From 15 to 25 lb. of kindling were used in this manner upon each test. In all calculations involving fuel this kindling was allowed for on the basis of 1 lb. of wood being equivalent to 0.4 lb. of the fuel employed.

In calculating item 72 (average interval between times in shaking and raking) each firing was considered as a time of shaking and raking, whether the fire was touched or not, other than to put on fresh fuel, also poking, leveling, or other working of the fire was so considered. Where the average interval between times of shaking and raking is the same as the average interval between firings (item 71) the fire was not touched between firings throughout the test.

TABLE 12 HOUSE-HEATING BOILER TESTS WITH REPRESENTATIVE FUELS, MADE AT ENGINEERING EXPERIMENT STATION, UNIVERSITY OF ILLINOIS, URBANA[1]

Test Number	Boiler	Kind of Fuel	Date 1908	Duration of Test (hours)	Average Pressures: Steam [Gage] pounds: Boiler	Average Pressures: Steam [Gage] pounds: Receiver	Average Pressures: Draft (in. of water): Flue	Average Pressures: Draft (in. of water): Over Fire	Average Temperatures (°F): Boiler Room	Average Temperatures (°F): Feed Water	Average Temperatures (°F): Flue Gas
				1	10	11	12	13	15	16	17
162	D1	Anthracite	February 24	8.77	5.0	2.0	.13	.10	83	171	585
166	....		March 2	16.55	4.5	2 0	.15	.11	85	171	435
186	....		May 4 & 5	23.15	4.0	2.0	.21	.12	76	178	604
163	D2	Anthracite	February 24	8.00	5.0	2.0	.12	.05	82	174	536
167	....		March 2	17.52	6.0	2.0	.08	.05	85	173	528
187	....		May 4 & 5	26.00	5.5	2.0	.12	.07	76	178	500
172	D1	Pocahontas	March 17	10.07	5.0	2.0	.17	.12	84	164	389
174	....		March 21	17.03	3.5	1.5	.16	.12	83	170	643
176	....		March 23 & 24	25.13	4.0	2.0	.18	.13	80	175	594
173	D2	Pocahontas	March 11	12.65	5.5	2.0	.12	.09	83	156	482
175	....		March 21	16.05	5.5	2.0	.13	.07	83	171	554
177	....		March 23 & 24	25.93	5.5	2.0	.13	.08	80	173	525
178	D1	Gas House Coke	April 11	8.43	5.5	2.0	.13	.08	69	166	560
199	....		May 21	9.57	4.0	2.0	.13	.11	92	177	528
180	....		April 7	15.83	4.0	2.0	.12	.10	80	175	568
213	...		June 18	17.15	5.0	2.0	.30	.09	94	170	410
201	....		May 22 & 23	23.70	3.5	2.0	.17	.14	80	172	536
182	....		April 17 & 18	26.23	3.5	2.0	.10	.09	79	175	605
179	D2	Gas House Coke	April 6	11.70	6.0	2.0	.12	.07	83	174	499
200	....		May 21	11.85	5.5	2.0	.09	.05	91	175	479
181	....		April 7	14.92	6.0	2.0	.12	.07	80	173	497
185	....		May 2	15.55	5.5	2.0	.10	.06	72	146	472
183	....		April 17 & 18	24.85	6.0	2.0	.11	.07	80	173	421
202	....		May 22 & 23	24.17	6.0	2.0	.10	.06	80	175	481
197	D1	Solvay Coke	May 19	10.63	4.0	2.0	.14	.11	88	178	511
195	....		May 18	15.17	4.0	2.0	.13	.11	86	178	513
192	....		May 11 & 12	26.53	3.5	2.0	.15	.12	82	179	504

207	D2	Solvay Coke	June 5	12.58	5.5	2.0	.06	.04	87	177	451
196	....	....	May 18	16.32	6.0	2.0	.09	.06	86	177	429
193	....	....	May 11 & 12	25.55	5.5	2.0	.08	.06	82	182	409
215	D1	Illinois, Williamson county	June 22	8.63	4.5	2.0	.33	.04	102	182	412
211	....	....	June 16	17.68	5.0	2.0	.29	.06	83	166	436
217	....	....	June 25 & 26	23.48	5.0	2.0	.45	.02	84	173	617
214	D2	Illinois, Williamson county	June 18	9.88	5.5	2.0	.07	.03	95	182	521
212	....	....	June 16	15.58	5.5	2.0	.09	.05	84	172	471
218	....	....	June 25 & 26	23.18	5.5	2.0	.19	.07	84	175	587
236	D1	Illinois, Macon county	July 27	9.78	5.0	2.0	.35	.05	97	176	523
234	....	....	July 24	16.73	5.0	2.0	.25	.07	94	177	545
232	....	....	July 22 & 23	24.58	5.0	2.0	.38	.07	91	179	483
237	D2	Illinois, Macon county	July 27	8.38	5.5	2.0	.13	.05	98	179	574
235	....	....	July 24	16.03	5.0	2.0	.16	.06	94	183	556
233	....	....	July 22 & 23	23 13	5.5	2.0	.13	.04	92	183	550
241	D1	Illinois, Vermilion county	July 31	7.97	4.5	2.0	.38	.03	97	169	544
243	....	....	August 3	16.45	5.0	2.0	.40	.06	97	170	535
239	....	....	July 29 & 30	24.47	4.5	2.0	.32	.05	94	175	560
242	D2	Illinois, Vermilion county	July 31	8.55	6.0	2.0	.18	.06	97	177	615
244	....	....	August 3	15.07	5.5	2.0	.17	.05	98	183	613
240	....	....	July 29 & 30	25.02	5.5	2.0	.16	.06	93	179	583

[1]See "7. Tabulated Data and Results," p. 20.

TABLE 12 HOUSE-HEATING BOILER TESTS WITH REPRESENTATIVE FUELS, MADE AT ENGINEERING EXPERIMENT STATION, UNIVERSITY OF ILLINOIS, URBANA—(*Continued*)

Test Number	Boiler	Kind of Fuel	Fuel as Fired (pounds)				Dry Fuel (pounds)			Total Ash and Refuse From Ash Pit (pounds)	Residual Fuel Removed (pounds)
			Wood	Coal	Coal Plus Wood	Corrected For Residual Fuel	Total Fired	Corrected For Residual Fuel	Actually Consumed (Corrected For Carbon in Ash)		
			20	21	21.1	21.2	23	23.1	23.2	24	25
162	D1	Anthracite	25	275	285	221	274	213	207	11.25	78.50
166	....	....	25	450	460	391	443	376	365	24.75	90.50
186	...	....	25	600	610	533	585	511	495	40.25	102.75
163	D2	Anthracite	30	315	327	225	314	216	206	14.75	115.25
167	...	....	30	525	537	452	517	435	414	39.00	105,50
187	....	....	30	735	747	637	716	610	587	47.00	146.50
172	D1	Pocahontas	15	225	231	217	226	213	204	14.00	21.00
174	....	....	15	375	381	369	373	361	352	17.75	24.00
176	....	....	15	600	606	595	594	584	564	36.25	29.00
173	D2	Pocahontas	20	315	323	303	317	297	277	28.25	32.00
175	....	....	20	420	428	406	419	398	378	31.50	33.00
177	....	....	20	630	638	621	625	608	581	44.50	26.75
178	D1	Gas House Coke	20	225	233	217	219	204	201	6.50	28.25
199	....	....	20	225	233	216	216	201	197	11.50	27.00
180	....	....	20	375	383	366	365	349	347	10.00	37.50
213	....	....	20	375	383	364	365	347	344	14.50	35.75
201	....	....	20	525	533	516	501	485	479	31.00	36.25
182	....	....	20	600	608	580	567	541	538	26.50	42.75
179	D2	Gas House Coke	25	315	325	296	301	275	270	11.75	40.50
200	....	....	25	315	325	297	301	275	268	17.75	40.00
181	....	....	25	420	430	396	410	378	373	15.50	52.00
185	...	....	25	420	430	401	414	386	382	10.00	53.00
183	....	....	25	630	640	603	597	563	559	28.00	53.00
202	....	....	25	630	640	613	602	577	569	38.25	49.50
197	D1	Solvay Coke	20	225	233	216	228	212	208	9.75	26.50
195	....	....	20	300	308	291	302	285	284	10.00	32.00
192	....	....	20	525	533	515	526	508	506	24.50	41.50

207	D2	Solvay Coke	25	315	325	302	321	298	298	14.50	37.25
196	....		25	420	430	404	422	396	388	26.00	42.50
193	....		25	630	640	610	631	601	590	29.50	58.25
215	D1	Illinois, Williamson county	20	225	233	224	215	207	203	14.75	14.50
211	....		20	450	458	446	430	418	416	20.25	31.00
217	....		20	600	608	594	567	554	549	41.25	29.25
214	D2	Illinois, Williamson county	25	315	325	307	305	288	281	21.75	24.00
212	....		25	525	535	516	502	484	476	40.00	27.50
218	....		25	735	745	729	695	680	673	55.50	32.50
236	D1	Illinois, Macon county	20	300	308	297	276	266	259	24.75	21.00
234	....		20	525	533	511	481	461	456	35.00	44.75
232	....		20	750	758	737	678	659	650	57.25	50.75
237	D2	Illinois, Macon county	25	315	325	309	291	277	267	26.75	27.50
235	....		25	630	640	616	578	556	545	44.25	51.75
233	....		25	840	850	834	760	746	736	67.25	47.00
241	D1	Illinois, Vermilion county	20	225	233	226	206	199	194	17.00	14.00
243	....		20	450	458	446	409	398	392	27.50	24.75
239	....		20	675	683	669	605	593	588	37.00	35.75
242	D2	Illinois, Vermilion county	25	315	325	311	287	275	266	29.00	19.50
244	....		25	525	535	522	478	467	457	36.50	26.75
240	....		25	840	850	823	753	729	717	56.25	40.50

TABLE 12 HOUSE-HEATING BOILER TESTS WITH REPRESENTATIVE FUELS, MADE AT ENGINEERING EXPERIMENT STATION, UNIVERSITY OF ILLINOIS, URBANA—(*Continued*)

Test Numb	Boiler	Kind of Fue	Proximate Analysis (per cent)								
			Fuel as Fired					Dry Fuel			
			Fixed Carbon	Volatile	Moisture	Ash	Sulphur	Fixed Carbon	Volatile	Ash	Sulphur
			26	27	28	29	34	26	27	29	34
162	D1	Anthracite	77.30	7.04	3.94	11.72	1.55	80.47	7.33	12.20	1.61
166	....		77.54	7.06	3.64	11.76	1.56	80.47	7.33	12.20	1.62
186	....		79.85	4.27	4.13	11.75	0.70	83.29	4.45	12.26	0.73
163	D2	Anthracite	77.30	7.04	3,94	11.72	1.55	80.47	7.33	12.20	1.61
167	....		77.54	7 06	3.64	11.76	1.56	80.47	7.33	12.20	1.62
187	....		79.85	4.27	4.13	11.75	0.70	83.29	4.45	12.26	0.73
172	D1	Pocahontas	73.36	19.50	1.97	5.17	0.98	74.83	19.89	5.28	1.00
174	....		73.32	19.49	2.02	5.17	0.98	74.83	19.89	5.28	1.00
176	....		73.32	19.49	2.02	5.17	0.98	74.83	19.89	5.28	1.00
173	D2	Pocahontas	73.36	19 50	1.97	5.17	0.98	74.83	19.89	5.28	1.00
175	....		73.32	19.49	2.02	5.17	0.98	74.83	19.89	5.28	1.00
177	....		73.32	19.49	2.02	5.17	0.98	74.83	19.89	5.28	1.00
178	D1	Gas House Coke	81.35	2.78	6.12	9.75	1.31	86.65	2.96	10.39	1.40
199	....		78.57	3.37	7.35	10.71	1.07	84.80	3.64	11.56	1.15
180	....		82.61	2.82	4.67	9.90	1.33	86 66	2.96	10.38	1.39
213	....		82.20	4.26	4.65	8.89	0.99	86.21	4.47	9.32	1.04
201	....		78.08	4.91	5.97	11.04	0.99	83.04	5.22	11.74	1.05
182	....		80.79	2.76	6.76	9.69	1.30	86.65	2.96	10.39	1.39
179	D2	Gas House Coke	80.28	2.74	7.36	9.62	1.30	86.66	2.96	10.38	1.40
200	....		78.57	3.37	7.35	10.71	1.07	84.80	3.64	11.56	1.15
181	....		82.61	2.82	4.67	9.90	1.33	86.66	2.96	10.38	1.39
185	....		85.20	1.73	3.71	9.36	0.92	88.48	1.80	9.72	0.96
183	....		80.79	2.76	6.76	9.69	1.30	86.65	2.96	10.39	1.39
202	....		78.08	4.91	5.97	11.04	0.99	83.04	5.22	11.74	1.05
197	D1	Solvay Coke	86.42	1.50	2.04	10.04	0.63	88.22	1.53	10 25	0.64
195	....		86.22	2.04	1.93	9.81	0.64	87.92	2.08	10.00	0,65
192	....		85.48	2.19	1.38	10.95	0.65	86.68	2.22	11.10	0.66

207	D2	Solvay Coke	85.63	2.70	1.31	10.36	0.66	86.76	2.74	10.50	0.67
196	....		86.22	2.04	1.93	9.81	0.64	87.92	2.08	10.00	0.65
193	....		85.48	2.19	1.38	10.95	0.65	86.68	2.22	11.10	0.66
215	D1	Illinois, Williamson county	49.60	34.20	7.83	8.37	1.92	53.81	37.11	9.08	2.08
211	...		46.86	38.48	6.21	8.45	2.23	49.96	41.03	9.01	2.38
217	....		48.95	34 68	6.69	9.68	2.04	52.46	37.17	10.37	2.19
214	D2	Illinois, Williamson county	47.03	37.60	6.10	9.27	1.99	50.09	40.04	9.87	2.12
212	....		46.86	38.48	6.21	8.45	2.23	49.96	41.03	9.01	2.38
218	....		48.95	34.68	6.69	9.68	2.04	52.46	37.17	10.37	2.19
236	D1	Illinois, Macon county	39.04	38.21	10.45	12.30	2.95	43.60	42.67	13.73	3.29
234	....		39.95	38.25	9.74	12.06	3.20	44.26	42.38	13.36	3.55
232	....		41.34	36.84	10.53	11.29	3.29	46.20	41.18	12 62	3.68
237	D2	Illinois, Macon county	39.04	38.21	10.45	12.30	2.95	43.60	42.67	13 73	3.29
235	...		39.95	38.25	9.74	12.06	3.20	44.26	42.38	13.36	3.55
233	....		41.34	36.84	10.53	11.29	3.29	46.20	41.18	12.62	3 68
241	D1	Illinois, Vermilion county	40.27	38.65	11.54	9.54	2.25	45.52	43.69	10.79	2.54
243	....		40.91	40.85	10.63	7.61	1.61	45.78	45.71	8.51	1.80
239	....		40.03	39.01	11.40	9.56	2.57	45.18	44.03	10.79	2.90
242	D2	Illinois, Vermilion county	40.27	38.65	11.54	9.54	2.25	45.52	43.69	10.79	2.54
244	....		40.91	40.85	10.63	7.61	1.61	45.78	45.71	8.51	1.80
240	....		40.03	39.01	11.40	9.56	2.57	45.18	44.03	10.79	2.90

TABLE 12 HOUSE-HEATING BOILER TESTS WITH REPRESENTATIVE FUELS, MADE AT ENGINEERING EXPERIMENT STATION, UNIVERSITY OF ILLINOIS, URBANA—(*Continued*)

Test Number	Boiler	Kind of Fuel	Residual Fuel (per cent)		Ash (per cent)		Dry Fuel per Hour		B. t. u. per Pound Fuel	
			Carbon	Earthy Matter	Carbon	Earthy Matter	Pounds	Per Sq. Ft. of Grate Surface	Dry	As Fired
			37	38	40	41	43	44	45	46
162	D1	Anthracite	70.50	29.50	46.07	53.93	24.29	5.68	13219	12698
166	....	....	66.82	33.18	38.45	61.55	22.72	5.31	13218	12737
186	....	....	65.01	34.99	36.76	63.24	22.07	5.16	13179	12635
163	D2	Anthracite	76.65	23.35	62.98	37.02	27.00	4.50	13219	12698
167	....	....	70.18	29.82	49.26	50.74	24.83	4.14	13218	12737
187	....	....	65.13	34.87	44.78	55.22	23.46	3.91	13179	12635
172	D1	Pocahontas	65.71	34.29	67.91	32.09	21.15	4.94	15055	14758
174	....	....	50.36	49.64	50.10	49.90	21.20	4.95	15055	14751
176	....	....	37.15	62.85	57.11	42.89	23.24	5.43	15055	14751
173	D2	Pocahontas	63.06	36.94	70.31	29.69	23.48	3.91	15055	14758
175	....	....	66.18	33.82	66.53	33.47	24.80	4.13	15055	14751
177	....	....	63.69	36.31	62.78	37.22	23.45	3.91	15055	14751
178	D1	Gas House Coke	46.71	53.29	34.66	65.34	24.20	5.65	12805	12021
199	....	....	49.05	50.95	28.76	71.24	21.00	4.91	12626	11698
180	....	....	38.11	61.89	18.89	81.11	22.05	5.15	12804	12206
213	....	....	44.06	55.94	15.53	84.47	20.23	4.73	12647	12059
201	....	....	38.41	61.59	18.05	81.95	20.46	4.78	12881	12112
182	....	....	54.06	45.94	9.61	90.39	20.63	4.82	12805	11939
179	D2	Gas House Coke	57.30	42.70	35.55	64.45	23.50	3.92	12804	11862
200	....	....	56.52	43.48	36.49	63.51	23.21	3.87	12626	11698
181	....	....	54.55	45.45	29.45	70.55	25.34	4.22	12804	12206
185	....	....	47.17	52.83	38.66	61.34	24.82	4.14	13028	12545
183	....	....	56.47	43.53	12.93	87.07	22.66	3.78	12805	11939
202	....	....	44.71	55.29	19.45	80.55	23.87	3.98	12881	12112
197	D1	Solvay Coke	53.57	46.43	31.98	68.02	19.91	4.66	12636	12378
195	....	....	45.65	54.35	10.10	89.90	18.79	4.39	12622	12378
192	....	....	37.37	62.63	8.65	91.35	19.15	4.47	12745	12569

207	D2	Solvay Coke	53.13	46.87	27.37	72.63	23.69	3.95	12823	12655
196	....		52.04	47.96	26.96	73.04	24.26	4.04	12622	12378
193	....		44.29	55.71	31.98	68.02	23.52	3.92	12745	12569
215	D1	Illinois, Williamson county	50.99	49.01	23.84	76.16	23.99	5.61	13227	12191
211	....		34.06	65.94	9.69	90.31	23.64	5.52	13207	12387
217	....		40.74	59.26	11.35	88.65	23.59	5.51	13079	12204
214	D2	Illinois, Williamson county	62.88	37.12	30.85	69.15	29.15	4.86	13092	12293
212	....		58.02	41.98	18.44	81.56	31.07	5.18	13207	12387
218	....		40.02	59.98	11.90	88.10	29.34	4.89	13079	12204
236	D1	Illinois, Macon county	39.51	60.49	25.02	74.98	27.20	6.36	12312	11025
234	....		37.88	62.12	12.69	87.31	27.56	6.44	12206	11017
232	....		31.18	68.82	12.60	87.40	26.81	6.26	12282	10989
237	D2	Illinois, Macon county	42.83	57.17	30.07	69.93	33.05	5.51	12312	11025
235	....		34.76	65.24	20.21	79.79	34.68	5.78	12206	11017
233	....		25.01	74.99	13.07	86.93	32.25	5.38	12282	10989
241	D1	Illinois, Vermilion county	41.04	58.96	27.61	72.39	24.97	5.83	12878	11392
243	....		40.04	59.96	15.93	84.07	24.19	5.65	13251	11842
239	..		30.07	69.93	11.96	88.04	24.23	5.66	12879	11411
242	D2	Illinois, Vermilion county	54.06	45.94	26.76	73.24	32.16	5.36	12878	11392
244	....		38.15	61.85	24.49	75.51	30.99	5.17	13251	11842
240	....		51.26	48.74	18.89	81.11	29.14	4.86	12879	11411

TABLE 12 HOUSE-HEATING BOILER TESTS WITH REPRESENTATIVE FUELS, MADE AT ENGINEERING EXPERIMENT STATION, UNIVERSITY OF ILLINOIS, URBANA—(*Continued*)

Test Number	Boiler	Kind of Fuel	Moisture in Steam (per cent)	Factor for Correcting Quality of Steam	Water (pounds) Fed to Boiler	Water (pounds) Corrected for Quality of Steam	Water (pounds) Equivalent from and at 212°F.	Factor of Evaporation	Water Per Hour (pounds) Equivalent from and at 212°F.	Water Per Hour (pounds) From and at 212°F. Per sq. ft. of Water-heating Surface
			47	48	49	50	52	51	53	54
162	D1	Anthracite	0.96	.9912	1349	1337	1397	1.0450	159	3.64
166	....		0.93	.9914	2518	2496	2608	1.0450	158	3.62
186	.		1.10	.9898	3568	3532	3665	1.0376	158	3.62
163	D2	Anthracite	0.68	.9937	1577	1567	1633	1.0419	204	2.69
167	....		0.61	.9944	3432	3413	3559	1.0428	203	2.68
187	....		0.88	.9918	4960	4919	5104	1.0376	196	2.58
172	D1	Pocahontas	1.00	.9909	1423	1410	1484	1.0522	147	3.36
174	....		1.07	.9902	2460	2436	2547	1.0456	150	3.43
176	....		1.03	.9905	3963	3925	4085	1.0407	163	3.73
173	D2	Pocahontas	0.69	.9937	2372	2357	2500	1.0606	198	2.61
175	....		0.95	.9913	3286	3257	3404	1.0450	212	2.79
177	....		0.77	.9929	5261	5224	5448	1.0428	210	2.77
178	D1	Gas House Coke	1.05	.9904	1387	1374	1443	1.0501	171	3.91
199	....		0.99	.9908	1404	1391	1445	1.0387	151	3.46
180	....		1.04	.9904	2393	2370	2466	1.0407	156	3.57
213	...		1.06	.9902	2513	2488	2602	1.0460	152	3.48
201	....		1.18	.9891	3538	3499	3653	1.0439	154	3.52
182	....		1.08	.9900	4047	4007	4170	1.0407	159	3.64
179	D2	Gas House Coke	0.84	.9922	2287	2269	2364	1.0419	202	2.66
200	....		0.80	.9926	2307	2290	2383	1.0407	201	2.65
181	....		0.78	.9928	2954	2933	3059	1.0428	205	2.70
185	....		0.82	.9926	3012	2990	3202	1.0710	206	2.72
183	....		0.75	.9931	4731	4698	4899	1.0428	197	2.60
202	....		0.93	.9914	4634	4594	4781	1.0407	198	2.61
197	D1	Solvay Coke	1.01	.9906	1629	1614	1675	1.0376	158	3.62
195	...		1.05	.9903	2270	2248	2333	1.0376	154	3.52
192	....		1.12	.9896	3940	3899	4042	1.0366	152	3.48

207	D2	Solvay Coke	0.87	.9919	2431	2411	2504	1.0387	199	2.62
196	....	....	0.85	.9921	3179	3154	3276	1.0387	201	2.65
193	....	....	0.86	.9920	4681	4644	4799	1.0334	188	2.48
215	D1	Illinois, Williamson county	0.98	.9909	1282	1270	1312	1.0334	152	3.48
211	...	....	1.09	.9900	2594	2568	2697	1.0501	153	3.50
217	....	....	1.09	.9899	3559	3523	3674	1.0428	156	3.57
214	D2	Illinois, Williamson county	1.01	.9906	1982	1963	2029	1.0334	205	2.70
212	....	....	1.01	.9907	3160	3131	3268	1.0439	210	2.77
218	....	....	1.03	.9905	4761	4716	4908	1.0407	212	2.79
236	D1	Illinois, Macon county	0.95	.9912	1494	1481	1540	1.0397	157	3.59
234	....	....	0.93	.9914	2598	2576	2676	1.0387	160	3.66
232	....	....	0.95	.9912	3719	3686	3821	1.0366	155	3.55
237	D2	Illinois, Macon county	0.61	.9943	1778	1768	1833	1.0366	219	2.89
235	....	....	0.79	.9926	3294	3270	3376	1.0324	211	2.78
233	.. .	....	0.77	.9928	4643	4610	4759	1.0324	206	2.72
241	D1	Illinois, Vermilion county	0.98	.9910	1205	1194	1250	1.0471	157	3.59
243	....	....	1.00	.9908	2488	2465	2578	1.0460	157	3.59
239	....	....	0.97	.9910	3718	3685	3835	1.0407	157	3.59
242	D2	Illinois, Vermilion county	0.70	.9935	1801	1789	1858	1.0387	217	2.86
244	....	....	0.68	.9937	3144	3124	3225	1.0324	214	2.82
240	....	....	0.75	.9930	4893	4859	5037	1.0366	201	2.65

TABLE 12 HOUSE-HEATING BOILER TESTS WITH REPRESENTATIVE FUELS MADE AT ENGINEERING EXPERIMENT STATION, UNIVERSITY OF ILLINOIS, URBANA—(*Continued*)

Test Number	Boiler	Kind of Fuel	Mean Load Carried		Percentage of Rated Capacity Developed (per cent)	Economic Results (pounds)			
						Equivalent Evaporation from and at 212° F. per pound		Fuel per Hour per 100 Sq. Ft. Radiating Surface	
			Sq. Ft. of Radiating Surface	Sq. Ft. of Radiating Surface plus Radiating Surface of Boiler		Fuel as Fired	Dry Fuel Consumed	As Fired	Dry
			55	55.1	56	57	58	59	60
162	D1	Anthracite	530	568	66.25	6.32	6.75	4.75	4.58
166	....		527	565	65.88	6.67	7.15	4.48	4.31
186	....		527	565	65.88	6.68	7.40	4.37	4.19
163	D2	Anthracite	680	783	63.26	7.26	7.93	4.14	3.97
167	....		677	780	62.98	7.87	8.60	3.81	3.67
187	....		653	756	60.74	8.01	8.70	3.75	3.59
172	D1	Pocahontas	496	528	61.25	6.84	7.27	4.40	4.32
174	....		500	538	62.50	6.90	7.24	4.33	4.24
176	....		543	581	67.88	6.87	7.24	4.36	4.28
173	D2	Pocahontas	660	763	61.40	8.25	9.03	3.63	3.56
175	....		707	810	65.77	8.38	9.01	3.58	3.51
177	....		700	803	65.11	8.77	9.38	3.42	3.35
178	D1	Gas House Coke	570	608	71.25	6.65	7.18	4.52	4.25
199	....		503	541	62.88	6.69	7.34	4.49	4.17
180	....		520	558	65.00	6.74	7.11	4.45	4.24
213	....		507	545	63.38	7.15	7.56	4.19	3.99
201	....		513	551	64.13	7.08	7.63	4.24	3.99
182	....		530	568	66.25	7.19	7.75	4.17	3.89
179	D2	Gas House Coke	673	776	62.60	7.99	8.76	3.76	3.49
200	....		670	773	62.33	8.02	8.89	3.74	3.46
181	....		683	786	63.53	7.72	8.20	3.89	3.71
185	....		687	790	63.91	7.99	8.38	3.75	3.61
183	....		657	760	61.12	8.12	8.76	3.69	3.45
202	....		660	763	61.40	7.80	8.40	3.84	3.62
197	D1	Solvay Coke	527	565	65.88	7.75	8.05	3.86	3.78
195	....		513	551	64.13	8.02	8.21	3.71	3.63
192	....		507	545	63.38	7.85	7.99	3.83	3.78

207	D2	Solvay Coke	663	766	61.67	8.29	8.55	3.62	3.57
196	....		670	773	62.33	8.11	8.44	3.70	3.62
193	....		627	730	58.33	7.87	8.13	3.81	3.75
215	D1	Illinois, Williamson county	507	545	63.38	5.86	6.46	5.12	4.73
211	....		510	548	63.75	6.05	6.48	4.95	4.64
217	....		520	558	65.00	6.19	6.69	4.86	4 54
214	D2	Illinois, Williamson county	683	786	63.53	6.61	7.22	4.55	4.27
212	....		700	803	65.12	6.33	6.87	4.73	4.44
218	....		707	810	65.77	6.73	7.29	4.45	4.15
236	D1	Illinois, Macon county	523	561	65.40	5.19	5.95	5.81	5.20
234	....		533	571	66.63	5.24	5.87	5.73	5.17
232	....		517	555	64.60	5.18	5.88	5.80	5.19
237	D2	Illinois, Macon county	730	833	67.91	5.93	6.87	5.07	4.55
235	....		703	806	65.40	5.48	6.19	5.47	4.93
233	....		687	790	63.91	5.71	6.47	5.25	4.69
241	D1	Illinois, Vermilion county	523	561	65.40	5.53	6.44	5.42	4.77
243	....		520	558	65.00	5.78	6.56	5.21	4.65
239	....		520	558	65.00	5.73	6.52	5.26	4.66
242	D2	Illinois, Vermilion county	723	826	67.30	5 97	6.98	5.03	4.45
244	....		713	816	66.30	6.18	7.06	4.86	4.35
240	....		670	773	62.30	6.12	7.03	4.91	4.35

TABLE 12 HOUSE-HEATING BOILER TESTS WITH REPRESENTATIVE FUELS MADE AT ENGINEERING EXPERIMENT STATION, UNIVERSITY OF ILLINOIS, URBANA—(*Continued*)

Test Number	Boiler	Kind of Fuel	Efficiency (per cent)		Fuel $1.00 per 2000 lb.		Fuel Fired at Each Firing (pounds)	Average Interval (hours)		Maximum Interval of Maintaining 2 lb. or more Steam Pressure Without Attention
			Boiler and Furnace	Plant	Cost in Cents per 100 sq. ft of Radiating Surface per hour (Mean Load Carried on Test)	Cost of Evaporating 1000 lb. of Water from and at 212° F. (cents)		Between Firings	Between Times of Shaking and Raking	
			61	62	64	65	70	71	72	73
162	D1	Anthracite	49.32	48.07	.238	7.91	75	2.19	2.19	3.17
166	....	....	52.24	50.58	.224	7.50	75	2.76	1.84	3.43
186	....	....	54.23	52 59	.219	7.27	75	2.47	2.19	3.00
163	D2	Anthracite	57.94	55.22	.207	6.89	105	2.67	2.00	4.55
167	....	....	62 84	59.68	.191	6.35	105	3.50	1.95	3.67
187	....	....	63.76	61.23	.188	6.24	105	3.71	2.89	4.67
172	D1	Pocahontas	46.64	44.76	.220	7.31	75	3.36	1.01	1.87
174	....	....	46.45	45.18	.217	7.24	75	3.41	0.71	2.00
176	....	....	46.45	44.98	.218	7 28	75	3.14	0.63	1.20
173	D2	Pocahontas	57.93	53.99	.182	6.06	105	4.22	0.84	2.63
175	....	....	57.80	54.87	.179	5.97	105	4.01	1.00	3.60
177	....	....	60.17	57.42	.171	5.70	105	4.32	0.93	2.82
178	D1	Gas House Coke	54.15	53.43	.226	7.52	75	2.81	2.81	1.70
199	....	....	56.15	55.23	.225	7.47	75	3.19	2.39	3.00
180	....	....	53,63	53.33	.223	7.42	75	3.17	3.17	3.00
213	....	....	57.73	57.26	.210	6.99	75	3.43	3.43	3.33
201	....	....	57.21	56.46	.212	7.06	75	3.39	2.63	3.33
182	....	....	58.45	58 16	.209	6.95	75	3.28	3.28	3.00
179	D2	Gas House Coke	66.08	65.05	.188	6.26	105	3.90	2.34	3.00
200	....	....	68.00	66.21	.187	6.23	105	3.95	1.98	3.00
181	....	....	61.85	61.08	.195	6.48	105	3.73	2.13	3.33
185	....	....	62.12	61.51	.188	6.26	105	3.89	1.95	3.33
183	....	....	66.07	65.69	.185	6.16	105	4.14	4.14	4.10
202	....	....	62,98	62.20	.192	6.41	105	4.03	2.42	4.00
197	D1	Solvay Coke	61 53	60.47	.193	6.45	75	3.54	3.54	3.66
195	....	....	62.82	62.58	.186	6 23	75	3.79	3.79	3.86
192	....	....	60.55	60.32	.192	6.37	75	3.79	3.79	3.66

207	D2	Solvay Coke....	64.40	63.27	.181	6.03	105	4.19	2.52	3.58
196	....	....	64.58	63.28	.185	6.17	105	4.08	3.26	4.00
193	....	....	61.61	60.47	.191	6.35	105	4.26	2.84	4.00
215	D1	Illinois, Williamson county....	47.17	46.42	.256	8.53	75	2.88	1.08	1.33
211	....	....	47.39	47.17	.248	8.26	75	2.95	1.47	1.66
217	....	....	49.40	48.99	.243	8.08	75	2.93	0.84	1.33
214	D2	Illinois, Williamson county....	53.26	51.93	.228	7.56	105	3.29	1.41	2.00
212	....	....	50.24	49.35	.237	7.90	105	3.12	1.42	2.00
218	....	....	53.83	53.26	.223	7.43	105	3.31	1.01	2.00
236	D1	Illinois, Macon county....	46.67	45.46	.291	9.65	75	2.45	0.98	1.33
234	....	....	46.45	45.94	.287	9.56	75	2.39	1.05	1.66
232	....	....	46.24	45.53	.290	9.67	75	2.46	0.95	1.66
235	D2	Illinois, Macon county....	53.89	51.95	.254	8.43	105	2.79	1.05	1.66
232	....	....	48.98	48.04	.275	9.12	105	2.67	1.14	1.33
233	....	....	50.88	50.18	.263	8.77	105	2.89	1.16	2.00
241	D1	Illinois, Vermilion county....	48.30	46.88	.271	9.06	75	2.66	0.66	1.00
243	....	....	47.81	47.14	.261	8.67	75	2.74	0.97	1.33
239	....	....	48.89	48.50	.263	8.74	75	2.72	0.94	1.66
242	D2	Illinois, Vermilion county....	52.35	50.61	.252	8.38	105	2.85	0.86	0.66
244	....	....	51.46	50.40	.243	8.09	105	3.01	1.16	1.66
240	....	....	52.72	51.80	.246	8.17	105	3.13	1.04	1.33

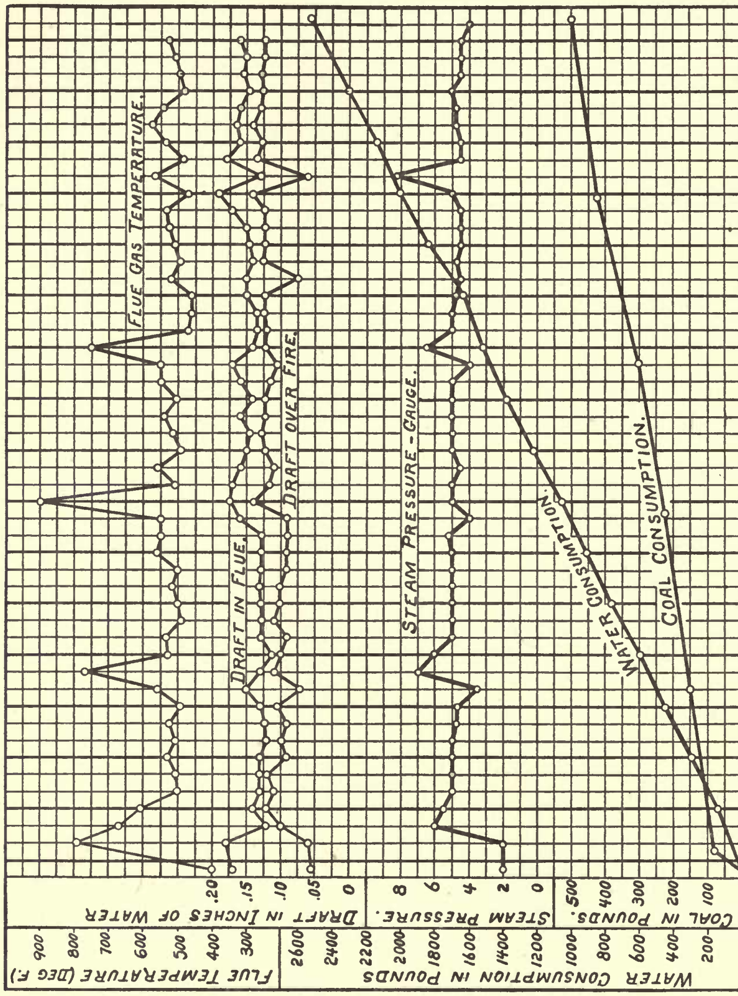

FIG. 18 GRAPHICAL LOG FOR TEST 166—BOILER D_1—ANTHRACITE COAL (House-heating boiler tests with representative fuels). (See "6. Test Data," p. 20).

FIG. 19 GRAPHICAL LOG FOR TEST 175—BOILER D_2—POCAHONTAS COAL

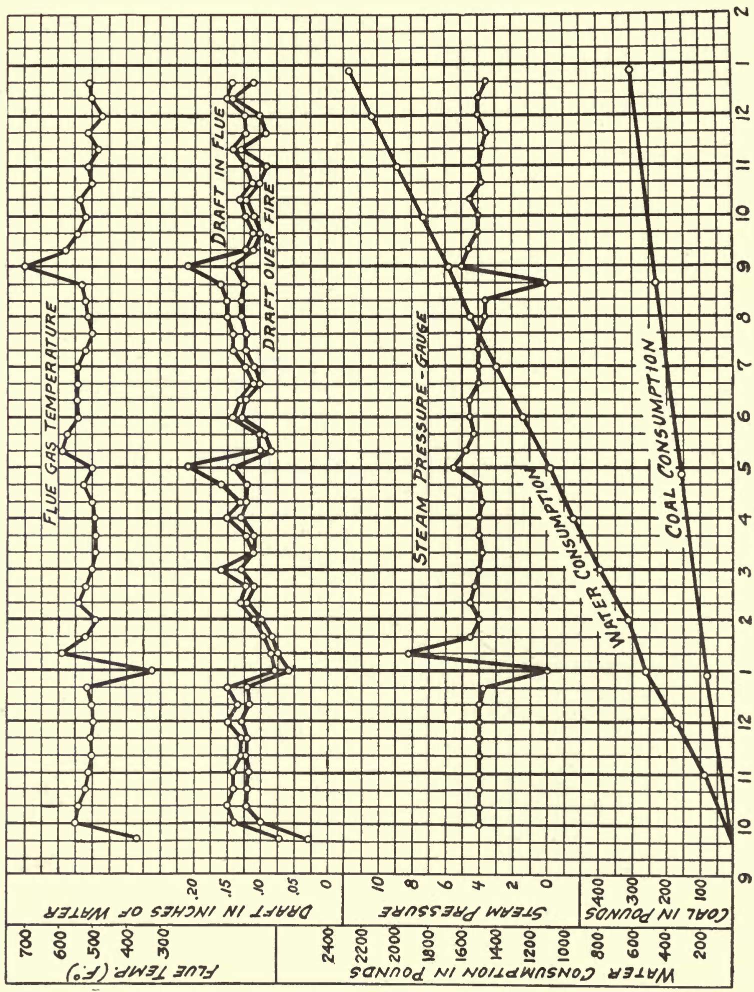

FIG. 20 GRAPHICAL LOG FOR TEST 195—BOILER D_1—SOLVAY COKE

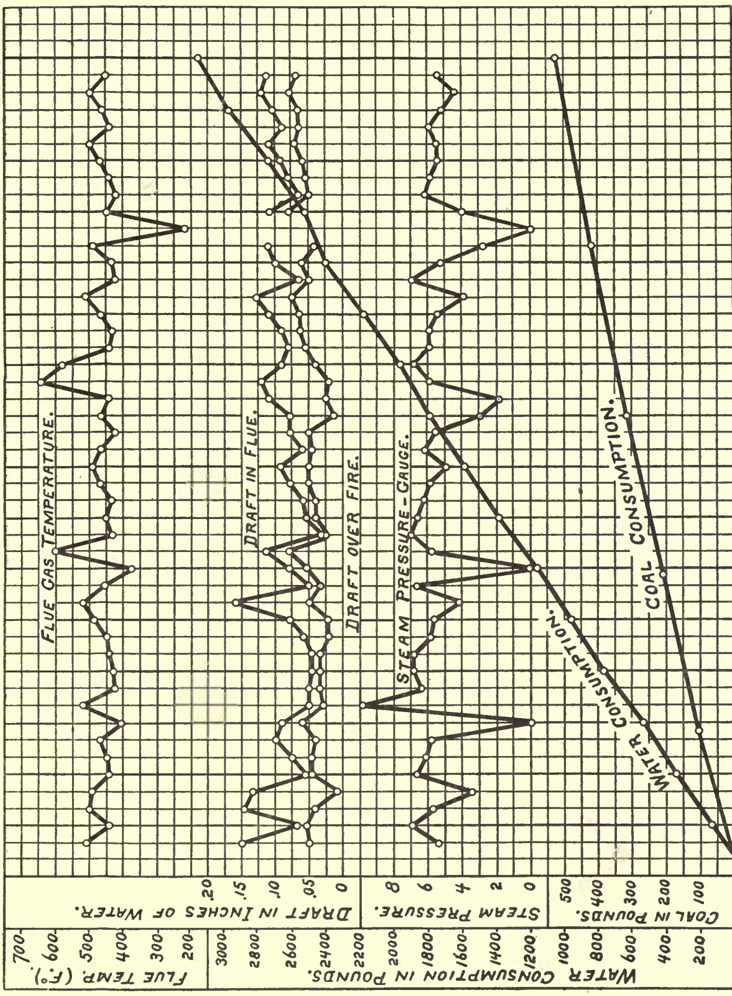

FIG. 21 GRAPHICAL LOG FOR TEST 212—BOILER D_2—ILLINOIS COAL (Williamson Co.)

TABLE 13

Flue Gas Analyses, House-heating Boiler Trials with Representative Fuels*

Kind of Fuel	Test No.	Length of Test (hours)	CO_2 per cent	O_2 per cent	Average	
					CO_2 per cent	O_2 per cent
Boiler D1						
Anthracite	162	8.76	3.6	14.6		
	186	23.15	6.4	11.4	5.0	13.0
Pocahontas	176	25.13	3.5	16.2	3.5	16.2
Gas House Coke	199	9.57	9.4	11.1		
	180	15.83	3.7	16.0		
	201	23.70	8.2	12.2		
	182	26.23	6.0	13.5	6.8	13.2
Solvay Coke	197	10.63	9.1	11.3		
	195	15.17	8.3	12.0	8.7	11.7
Illinois, Williamson county	215	8.63	6.7	12.8		
	217	23.48	6.8	12.8	6.8	12.8
Illinois, Macon county	234	16.73	6.2	13.4	6.2	13.4
Boiler D2						
Anthracite	163	8.00	8.8	10.7		
	167	17.52	9.9	9.7		
	187	26.00	8.9	9.6	9.2	10.0
Pocahontas	175	16.05	7.6	10.1		
	177	25.93	8.7	9.3	8.2	9.7
Gas House Coke	179	11.70	9.3	7.4		
	200	11.85	15.3	4.4		
	185	15.55	14.4	5.0		
	181	14.92	12.0	6.7		
	183	24.85	11.7	6.9		
	202	24.17	13.5	6.3	12.7	6.1
Solvay Coke	209	12.57	14.3	4.7		
	196	16.33	12.1	7.3	13.2	6.0
Illinois, Williamson county	214	9.88	10.4	6.7		
	212	15.58	11.7	4.5		
	218	23.18	5.1	14.8	9.1	8.7
Illinois, Macon county	235	16.03	11.4	5.9	11.4	5.9

*See "7. Tabulated Data and Results," p. 20.

TABLE 14

Comparison of Flue Gas Analyses Taken at Different Times During Test, Boiler D_2, House-heating Boiler Trials with Representative Fuels

Fuel	Time of Starting Sample	Length of Time of Collecting Sample (min.)	When Taken	CO_2 per cent	O_2 per cent
Anthracite	10:00 A. M.	20	Just after 2nd firing	7.2	9.6
	11:00 A. M.	35	1 hour after 2nd firing	9.0	10.0
	12:00 M.	45	2 hours after 2nd firing	8.4	10.4
	2:05 P. M.	60	45 minutes after 3rd firing	11.1	7.9
Gas House Coke	9:45 A. M.	60	37 minutes after 1st firing	14.0	5.7
	12:25 P. M.	60	15 minutes after 2nd firing	14.4	3.9
	2:10 P. M.	80	2 hours after 2nd firing	14.8	5.3
	4:20 P. M.	20	2 minutes after 3rd firing	11 3	7.3
	5:10 P. M.	30	52 minutes after 3rd firing	16.5	3.6
	6:00 P. M.	60	1 hour 42 min. after 3rd firing	15.6	4.4
Solvay Coke	9:15 A. M.	45	1 hour after 1st firing*	15.1	4.1
	10:45 A. M.	30	2 hours 30 min. after 1st firing **	12.2	7.0
	10:00 A. M.	60	47 minutes after 1st firing	13.8	5.6
	12:00 M.	60	2nd firing at 12:45	10.8	9.2
	2:35 P. M.	60	1 hour 50 min. after 2nd firing	13.2	4.6
	4:30 P. M.	40	3 hours 45 min. after 2nd firing	10.5	9.8
Illinois, Williamson county	9:25 A. M.	30	30 minutes after 1st firing†	7.9	9.8
	10:00 A. M.	30	65 minutes after 1st firing††	9.7	8.1
	11:52 A. M.	30	Just after 2nd firing	8.0	8.7
	12:30 P. M.	30	40 minutes after 2nd firing	12.4	4.6
	2:30 P. M.	34	1 hour before 3rd firing	13.3	6.2
	3:35 P. M.	..	Just after 3rd firing	11.4	2.8

* Fire hot and thick. ** Fire thin, with several holes.
Both of these samples on test No. 207. Other four coke samples on test No. 196.
† Fire badly caked. †† Fire clear and bright.

TABLE 15

SMOKE CHART RECORD, HOUSE-HEATING BOILER TRIALS WITH REPRESENTATIVE FUELS

Boiler No.	Kind of Fuel	Test No.	Number of Firing after which Smoke Record was Made	Color or Condition of Smoke	Maximum Density of Smoke Recorded		Percent of Firing Interval During Which Smoke Was Produced	Percent of Firing Interval During Which No Smoke Was Produced	Percent of Black Smoke for Test Based Upon the Intervals Observed
					per cent	No. on Ringelmann Chart	per cent	per cent	per cent
D1	Gas House Coke..........	199	3rd	....	40	2	7	93	2
D1	"	213	1st	Dense Yellow.....	50	2.5	9	91	3
D2	"	200	3rd	....	20	1	7	93	1
D2	"	185	3rd	....	40	2	6	94	2
D1	Solvay Coke............	195	1st	Gray Yellow......	50	2.5	7	93	2
D1	"	192	2d &6 th	Light Gray..	10	0.5	5	95	0
D2	"	196	1st	Light Yellow......	50	2.5	10	90	3
D2	"	193	1st	Light Gray..	60	3	15	85	3
D1	Williamson county, Illinois.............	211	3rd	....	40	2	50	50	14
D1	"	217	2nd	Yellow,black,gray	70	3.5	49	51	11
D2	"	214	1st	....	60	3	48	52	13
D1	Macon county, Illinois...	236	2nd	....	70	3.5	48	52	16
D1	"	234	2nd	....	40	2	40	60	13
D1	"	232	2nd	....	50	2.5	64	36	24
D2	"	237	2nd	....	60	3	61	39	22
D2	"	235	2nd	....	60	3	44	56	17
D2	"	233	2nd	....	60	3	27	73	10
D1	Vermilion county, Illinois.............	241	3rd	....	60	3	44	56	18
D1	"	243	4th	....	50	2.5	34	66	13
D1	"	239	2nd	....	60	3	56	44	24
D2	"	242	3rd	....	70	3.5	60	40	23
D2	"	244	4th	....	60	3	50	50	15
D2	"	240	2nd	....	50	2.5	45	55	16

APPENDIX B

TABLE 16 TESTS OF FUEL IN HOUSE-HEATING BOILER AT ST. LOUIS*

Test No.	Designation of Fuel	Description of Fuel	Duration of Trial hours	Average Pressures: Steam Pressure in Boiler (gage)	Average Pressures: Barometer (lb. per sq. in.)	Average Pressures: Draft in. of water: Between Damper and Boiler	Average Pressures: Draft in. of water: Over Fire	Average Pressures: Draft in. of water: In Ashpit
			1	10	11.1	12	13	13.1
45	Arkansas No. 13	Briquets, round	8.33	2.2	14.39	0.34	0.07	0.04
58	Illinois No 1	Coal, run-of-mine	7.92	1.9	14.36	.33	.07	.03
59	"	"	8.00	1.9	14.45	.36	.05	.03
48	Illinois No. 7 .E	Briquets, round	8.00	1.7	14.45	.33	.06	.03
39	Illinois No. 9 C.		8.30	1.7	14.54	.36	.07	.04
13	Illinois No. 12 BW	Briquet, square, slack	8.25	3.8	14.39	.21	.06	.05
52	Illinois No. 19 E	Coal, egg	7.80	2.4	14.56	.31	.03	.03
53	"	"	8.25	2.3	14.41	.35	.05	.04
54	"	"	8.06	2.1	14.30	.32	.03	.02
55	"	"	7.83	1.3	14.35	.36	.03	.02
9	Illinois No. 29 AW	Briquets, round	7.88	3.4	14.46	.24	.10	.06
12	Illinois No. 29 B	Briquets, round, slack	7.20	2.2	14.51	.23	.08	.07
33	Illinois No. 31.	Briquets, square	7.83	2.7	14.37	.29	.13	.10
34	"	"	8.08	2.9	14.34	.28	.10	.06
44	"	Briquets, round	8.33	1.8	14.40	.36	.07	.04
43	Illinois No. 33	"	7.83	2.2	14.34	.32	.08	.05
37	Indiana No. 1 B	"	8.33	2.4	14.60	.35	.13	.07
36	Indiana No. 5 B	"	8.41	2.7	14.26	.34	.13	.08
38	Indiana No. 6 B	Briquets, square	7.88	2.8	14.64	.35	.09	.06
10	Indian Territory No.2 BW	Briquets, square, slack	7.92	3.3	14.59	.25	.12	....
11	Indian Territory No. 2 B.	Briquets, round, slack	7.87	4.3	14.51	.22	.05	.04
1	Kansas No. 2 B	"	8.00	4.1	14.46	.22	.05	.03
40	"	Briquets, square	8.25	2.5	14.36	.36	.09	.06
21	Maryland No. 2.	Briquets, round	8.00	2.9	14.65	.28	.12	.09
22	"	"	7.50	3.2	14.55	.23	.11	.10
23	"	"	8.00	3.6	14.51	.23	.11	.10
20	"	Coal, run-of-mine	7.88	2.2	14.52	.25	.13	.09
2	Missouri No. 10	Briquets, round, slack	7.66	3.4	14.68	.24	.04	.03
3	"	"	7.83	3.1	14.46	.21	.07	.05
4	"	"	7.82	3.2	14.54	.25	.08	.06
5	"	"	8.13	2.0	14.59	.26	.10	.05
28	Pennsylvania No. 18	Briquets, round	8.00	3.9	14.37	.18	.09	.08
29	"	"	8.00	4.6	14.44	.18	.07	.06
30	"	Briquets. square	7.70	3.3	14.51	.22	.11	.10
31	"	"	8.00	3.4	14.60	.29	.12	.10
46	"	"	8.13	2.1	14.40	.36	.03	.01
24	"	Coal, run-of-mine	8.00	3.0	14.55	.22	.10	.09
25	"	"	8.00	3.1	14.41	.22	.13	....
32	Pennsylvania No. 19	Briquets, round	6.58	3.6	14.33	.27	.11	.07
15	"	Coal, run-of-mine	7.50	3.4	14.43	.23	.11	.10
26	Pennsylvania No. 20	Briquets, square	8.00	3.4	14.48	.23	.12	....
27	"	"	8.00	3.3	14.40	.22	.11	.
41	Pennsylvania No. 20 W	Briquets, round	7.81	3.3	14.30	.32	.07	.06
42	"	"	5.20	2.9	14.32	.33	.09	.08
16	Pennsylvania No. 22	"	7.83	3.7	14.46	.22	.11	.08
17	"	"	8.08	3.5	14.28	.21	.09	.08
18	"	Briquets, square	8.00	1.6	14.36	.23	.09	.07
19	"	"	8.05	2.4	14.36	.23	.12	.11
14	"	Coal, run-of-mine	7.58	3.8	14.55	.23	.10	.07
47	Pennsylvania No. 15 (one half) and Rhode Island No. 1 (one-half).	Briquets, round	8.23	2.0	14.51	.34	.07	.03
56	Pennsylvania No 18 (one-fourth) and Miscellaneous No.9(three-fourths)	"	8.16	1.6	14.38	.34	.04	.02
57	"	"	7.00	2.2	14.47	.36	.07	.04
35	Pennsylvania No. 18 (one-half) and Rhode Island No. 1 (one-half).	"	5.66	3.2	14.31	.29	.10	.07
49	Pennsylvania No. 18 (three-fourths) and Miscellaneous No. 9 (one-fourth).	"	8.23	3.0	14.45	.30	.06	.04
50	Pennsylvania No. 18 (one-half) and Miscellaneous No. 9 (one-half).	"	7.83	2.2	14.40	.34	.07	.04
51	"	"	8.00	2.5	14.46	.33	.04	.02
7	Virginia No. 5 B	"	8.00	3.6	14.46	.24	.12	.10
8	"	"	7.80	4.8	14.35	.19	.09	.07

*See "15. Data and Results," p. 58.

TABLE 16 TESTS OF FUEL IN HOUSE-HEATING BOILER AT ST. LOUIS—*(Continued)*

Test No.	Designation of Fuel	Average Temperature (°F): External Air	Average Temperature (°F): Boiler Room	Average Temperature (°F): Feed Water in Weigh Tank	Average Temperature (°F): Gases Escaping from Boiler	Fuel as Fired pounds	Dry Fuel pounds	Total Dry Fuel Fired minus Dry Fuel Equivalent to the Carbon in the Ash pounds	Total Ash and Refuse from Ashpit (pounds)
		14	15	16	17	21	23	23.2	24
45	Arkansas No. 13	50	81	145	695	777	765	731	137
58	Illinois No. 1	64	88	121	710	854	739	706	151
59	"	46	73	126	720	874	756	728	128
48	Illinois No. 7 E	45	77	141	650	965	907	874	237
39	Illinois No. 9 C	58	83	137	855	871	824	789	195
13	Illinois No. 12 BW	69	92	143	...	666	613	587	98
52	Illinois No. 19 E	59	88	138	600	817	757	727	114
53	"	66	88	128	720	927	859	827	122
54	"	62	85	135	635	811	752	725	104
55	"	72	93	123	850	764	708	685	87
9	Illinois No. 29 AW	31	70	149	...	750	658	648	68
12	Illinois No. 29 B	46	79	147	...	735	688	671	106
33	Illinois No. 31	80	91	106	570	813	738	725	112
34	"	82	96	101	400	836	759	743	139
44	"	51	82	138	795	968	901	880	144
43	Illinois No. 33	50	81	146	600	974	882	761	333
37	Indiana No. 1 B	57	91	120	815	1104	1056	1037	120
36	Indiana No. 5 B	63	90	103	730	929	890	868	134
38	Indiana No. 6 B	45	82	140	715	815	768	750	144
10	Indian Territory No. 2 BW	33	71	150	...	736	720	686	100
11	Indian Territory No. 2 B	42	76	158	...	737	721	700	126
1	Kansas No. 2 B	40	72	145	...	667	648	...	113
40	"	48	84	135	665	800	772	743	172
21	Maryland No. 2	31	74	150	...	652	628	612	73
22	"	30	80	146	...	560	540	534	28
23	"	41	73	143	...	650	626	611	67
20	"	32	71	144	...	520	511	502	34
2	Missouri No. 10	32	70	151	...	1159	1031	986	258
3	"	57	83	149	...	769	684	651	189
4	"	27	69	139	...	819	729	695	193
5	"	18	67	154	...	1036	922	898	136
28	Pennsylvania No. 18	46	81	140	...	580	537	531	37
29	"	54	85	144	...	662	604	598	34
30	"	42	83	146	...	525	500	496	31
31	"	58	81	146	550	550	524	516	68
46	"	44	80	133	685	653	636	610	110
24	"	43	78	144	...	550	539	527	47
25	"	42	74	145	...	550	530	518	47
32	Pennsylvania No. 19	86	96	112	675	541	532	527	41
15	"	55	85	142	...	456	447	438	27
26	Pennsylvania No. 20	44	77	145	...	525	493	484	55
27	"	52	85	141	...	550	516	508	48
41	Pennsylvania No. 20 W	48	84	146	570	594	587	577	56
42	"	45	76	134	620	388	383	374	53
16	Pennsylvania No. 22	48	78	141	...	550	538	520	117
17	"	63	..	138	...	538	526	515	72
18	"	47	79	140	...	553	533	503	92
19	"	46	77	140	...	551	531	504	84
14	"	47	81	144	...	492	483	459	97
47	Pennsylvania No. 15 (one-half) and Rhode Island No. 1 (one-half)	45	77	147	665	652	647	616	112
56	Pennsylvania No. 18 (one-fourth) and Miscellaneous No. 9 (three-fourths)	50	80	126	800	644	637	606	112
57	"	53	83	125	730	652	645	613	117
35	Pennsylvania No. 18 (one-half) and Rhode Island No. 1 (one-half)	84	99	102	705	489	482	475	46
49	Pennsylvania No. 18 (three-fourths) and Miscellaneous No. 9 (one-fourth)	47	79	142	550	648	636	609	130
50	Pennsylvania No. 18 (one-half) and Miscellaneou2 No. 9 (one-half)	47	80	140	630	646	638	596	133
51	"	49	79	139	620	651	643	598	142
7	Virginia No. 5 B	37	72	157	...	712	680	639	154
8	"	45	77	155	...	613	585	549	134

TABLE 16 TESTS OF FUEL IN HOUSE-HEATING BOILER AT ST. LOUIS—(*Continued*)

Test No.	Designation of Fuel	Proximate Analysis of Fuel as Fired per cent				Ultimate Analysis of Dry Fuel per cent					
		Fixed Carbon	Volatile Matter	Moisture	Ash	Carbon	Hydrogen	Oxygen	Nitrogen	Sulphur	Ash
		26	27	28	29	30	31	32	33	34	35
45	Arkansas No. 13	68.30	15.11	1.49	15.10	75 05	3.84	1.81	1.35	2.62	15.33
58	Illinois No. 1	41.39	33.15	13.49	11.97	64.88	4.45	10.71	1.03	5.09	13.84
59	"	41.39	33.15	13.49	11.97	64 88	4.45	10.71	1.03	5.09	13.84
48	Illinois No. 7 E	40.31	30.09	6.06	23.51	59.48	3.54	5.70	.83	5.42	25.03
39	Illinois No. 9 C	47.63	33.55	5.43	13.39	68.44	4.44	8.30	.94	3.72	14.16
13	Illinois No. 12 BW	49.47	31.55	7.93	11.05	71.14	4.39	8.90	1.12	2.45	12.00
52	Illinois No. 19 E	51.22	31.00	7.33	10.45	.....	....	.....	....	2.76	.....
53	"	51.22	31.00	7.33	10.45	.....	....	.....	....	2.76	.....
54	"	51.22	31.00	7.33	10.45	.....	....	.....	....	2.76	.....
55	"	51.22	31.00	7.33	10 45	.....	....	.....	....	2.76	.....
9	Illinois No. 29 AW	43.99	37 16	12.29	6.56	72.22	4.92	10.25	1.07	4.06	7.48
12	Illinois No. 29 B	44.21	37.44	6.42	11.93	67.10	4.59	10.30	1.00	4 26	12.75
33	Illinois No. 31	43.90	33.03	9.17	13.90	66.14	4.33	8.93	1.01	4.29	15.30
34	"	43.90	33.03	9.17	13.90	66.14	4.33	8.93	1.01	4.29	15.30
44	"	42 85	35.21	6.98	14.96	66.75	4.85	7.33	.93	4.06	16.08
43	Illinois No. 33	40.75	28.25	9.47	21.53	60.07	3.93	9.47	1.03	1.72	23.78
37	Indiana No 1 B	44.78	36.21	4.34	14.67	65.26	4.58	10.84	1.20	2.78	15.34
36	Indiana No. 5 B	48.91	35.74	4.20	11.15	70.47	4.85	7.53	.94	4.57	11.64
38	Indiana No. 6 B	43.16	37.83	5.72	13.29	66.48	4.76	8.42	1.07	5.17	14.10
10	Indian Territory No. 2 BW	54.51	35.86	2.19	7.44	75.69	4.84	8.76	1.53	1.57	7.61
11	Indian Territory No. 2 B	51.31	34 60	2.15	11.94	71.96	4.56	8.09	1.45	1.74	12.20
1	Kansas No. 2 B	46.78	31.67	2.78	18.77	66.00	4.35	4.90	.96	4.48	19.31
40	"	47.58	29.09	3.47	19.86	63.78	4.01	5.92	1.03	4.69	20.57
21	Maryland No. 2	68.54	21.14	3 63	6.69	82.41	4.74	3.40	1.62	.89	6 94
22	"	68 54	21.14	3.63	6.69	82 41	4.74	3.40	1.62	.89	6.94
23	"	68.54	21.14	3.63	6.69	82.41	4.74	3.40	1.62	.89	6.94
20	"	71.25	18.69	1.69	8 37	.....	....	....	....	.92	....
2	Missouri No 10	38.67	32.24	11.03	18 06	.....	....	....	....	4.18	....
3	"	38.67	32.24	11.03	18.06	.....	....	....	....	4.18	....
4	"	38.67	32.24	11.03	18.06	.....	....	....	....	4.18	....
5	"	38.67	32.24	11.03	18.06	....	....	....	....	4.18	...
28	Pennsylvania No. 18	64.61	19.45	7.43	8.51	80.80	4.44	2.88	1.16	1.53	9.19
29	"	64.61	19.45	7.43	8.51	80.80	4.44	2.88	1.16	1.53	9.19
30	"	69.14	18.43	4.71	7.72	81.77	4.40	3.22	1.26	1.25	8.10
31	"	69.14	18.43	4.71	7.72	81.77	4.40	3.22	1.26	1.25	8.10
46	"	62.80	24.23	2.55	10.42	78.65	4.36	3.38	.88	2.04	10.69
24	"	71.55	16.71	1.96	9.82	.....	....	...	....	1.91	.....
25	"	71.88	16.46	3.56	8.10	...	....	...	....	1.76	.....
32	Pennsylvania No. 19	55.24	33.50	1.75	9.51	75.91	4.52	7.16	1.35	1.38	9.68
15	"	57.20	31.71	2.03	9.06	.....	....	....	....	1.15	.....
26	Pennsylvania No. 20	64.38	19.23	6.16	10.23	78.13	4.20	2.83	1.09	2.85	10.90
27	"	64 38	19.23	6.16	10.23	78.13	4.20	2.83	1.09	2.85	10.90
41	Pennsylvania No. 20 W	67.74	20.58	1.23	10.45	79.20	4.56	1.52	1.12	3.02	10.58
42	"	67.74	20 58	1.23	10.45	79.20	4.56	1.52	1.12	3 02	10.58
16	Pennsylvania No. 22	55.12	32.11	2.21	10.56	75.72	4.52	6.41	1.39	1.16	10.80
17	"	55.12	32.11	2.21	10.56	75.72	4.52	6.41	1.39	1.16	10.80
18	"	54.27	30.57	3.55	11.61	75.93	4.58	5.10	1.24	1.11	12.04
19	"	54.27	30.57	3.55	11.61	75.93	4.58	5.10	1.24	1.11	12.04
14	"	57.96	29.45	1.77	10.82	.....	....	....	....	.90	.....
47	Pennsylvania No. 15 (one-half) andRhode Island No. 1 (one-half)	69.71	15.96	.74	13.59	77.47	3.05	2.66	.49	2.64	13.69
56	Pennsylvania No. 18 (one-fourth) and Miscellaneous No. 9 (three-fourths)	69.24	15.87	1.06	13.83	76.03	2.81	4.92	.81	1.45	13.98
57	"	69.24	15.87	1.06	13.83	76.03	2.81	4.92	.81	1.45	13.98
35	Pennsylvania No. 18 (one-half) and Rhode Island No. 1 (one-half)	70.34	16.39	1.34	11.93	77.79	3.46	4.74	.53	1.39	12.09
49	Pennsylvania No. 18 (three-fourths) and Miscellaneous No. 9 (one-fourth)	69.52	15.05	1.83	13.60	77.21	3.12	3.48	.70	1.64	13.85
50	Pennsylvania No. 18 (one-half) and Miscellaneous No 9 (one-half)	69.67	13.73	1.30	15.30	70.93	2.81	8.80	.75	1.21	15.50
51	"	69.67	13.73	1.30	15.30	70.93	2.81	8.80	.75	1.21	15.50
7	Virginia No. 5 B	65.93	14.28	4.52	15.27	76.18	3.67	2.52	.81	.83	15.99
8	"	65.93	14.28	4.52	15.27	76.18	3.67	2.52	.81	.83	15.99

TABLE 16 TESTS OF FUEL IN HOUSE HEATING BOILER AT ST. LOUIS—(*Continued*)

Test No.	Designation of Fuel	Analysis of Ash and Refuse per cent: Carbon	Analysis of Ash and Refuse per cent: Earthy Matter	Fuel per hour pounds: As Fired	Fuel per hour pounds: Dry	Burned per square foot of Grate Surface: As Fired	Burned per square foot of Grate Surface: Dry	British thermal units per pound of Fuel: Dry	British thermal units per pound of Fuel: As Fired
		37	38	43	43.1	44.1	44	45	46
45	Arkansas No. 13	22.06	77.94	93	92	6.89	6.81	13112	12917
58	Illinois No 1	18.40	81.60	108	93	8.00	6.89	12178	10535
59	"	18.40	81.60	109	95	8.08	7.04	12178	10535
48	Illinois No. 7 E	10.02	89.98	121	113	8.96	8.37	10667	10021
39	Illinois No. 9 C	15.00	85.00	105	99	7.78	7.33	12385	11713
13	Illinois No. 12 BW	23.85	76.15	81	74	6.00	5.48	12958	11930
52	Illinois No. 19 E	22.05	77.95	105	97	7.78	7.18	12411	11501
53	"	22.05	77.95	112	104	8.30	7.70	12411	11501
54	"	22.05	77.95	101	93	7.48	6.89	12411	11501
55	"	22.05	77.95	98	90	7.26	6.67	12411	11501
9	Illinois No. 29 AW	13.95	86.05	95	84	7.04	6.22	13306	11671
12	Illinois No. 29 B	13.56	86.44	102	96	7.56	7.11	12562	11756
33	Illinois No. 31	9.47	90.53	104	94	7.70	6.96	12024	10921
34	"	9.47	90.53	103	94	7.63	6.96	12024	10921
44	"	11.97	88.03	116	108	8.59	8.00	11995	11158
43	Illinois No. 33	26.85	73.15	124	113	9.19	8.38	10782	9761
37	Indiana No. 1 B	13.13	86.87	133	127	9.86	9.41	11907	11390
36	Indiana No. 5 B	14.79	85.21	110	106	8.15	7.85	12970	12425
38	Indiana No. 6 B	10.48	89.52	103	97	7.63	7.18	12557	11839
10	Indian Territory No. 2 BW	32.11	67.89	93	91	6.89	6.74	13865	13561
11	Indian Territory No. 2 B	15.05	84.95	94	92	6.96	6.82	13196	12912
1	Kansas No. 2 B	.....	.....	83	81	6.15	6.00	12132	11795
40	"	13.53	86.47	97	94	7.18	6.96	11855	11444
21	Maryland No. 2	22.64	77.36	82	79	6.08	5.85	14694	14161
22	"	22.64	77.36	75	71	5.56	5.26	14694	14161
23	"	22.64	77.36	81	78	6.00	5.78	14694	14161
20	"	27.30	72.70	66	65	4.89	4.72	14473	14229
2	Missouri No. 10	13.89	86.11	151	135	11.20	10.00	11588	10310
3	"	13.89	86.11	98	87	7.26	6.44	11588	10310
4	"	13.89	86.11	105	93	7.78	6.89	11588	10310
5	"	13.89	86.11	127	113	9.41	8.37	11588	10310
28	Pennsylvania No. 18	16.64	83.36	73	67	5.41	4.97	14408	13338
29	"	16.64	83.36	82	76	6.07	5.63	14408	13338
30	"	12.02	87.98	68	65	5.04	4.81	14559	13873
31	"	12.02	87.98	69	66	5.11	4.89	14559	13873
46	"	22.54	77.46	80	78	5.93	5.78	14038	13680
24	"	25.38	74.62	69	67	5.11	4.97	14096	13820
25	"	25.38	74.62	69	66	5.11	4.89	14377	13865
32	Pennsylvania No. 19	10.44	89.56	82	81	6.08	6.00	13889	13646
15	"	31.05	68.95	61	60	4.52	4.44	13996	13712
26	Pennsylvania No. 20	15.53	84.47	66	62	4.89	4.59	14064	13198
27	"	15.53	84.47	69	65	5.11	4.82	14064	13198
41	Pennsylvania No. 20 W	17.04	82.96	76	75	5.63	5.56	14069	13896
42	"	17.04	82.96	75	74	5.56	5.48	14069	13896
16	Pennsylvania No. 22	15.01	84.99	70	69	5.18	5.11	13867	13561
17	"	15.01	84.99	67	65	4.96	4.82	13867	13561
18	"	30.83	69.17	69	67	5.11	4.96	13764	13275
19	"	30.83	69.17	68	66	5.04	4.89	13764	13275
14	"	22.96	77.04	65	64	4.82	4.74	13812	13568
47	Pennsylvania No. 15 (one-half) and Rhode Island No. 1 (one-half)	24.55	75.45	79	79	5.85	5.85	12887	12793
56	Pennsylvania No. 18 (one-fourth) and Miscellaneous No. 9 (three fourths)	24.20	75.80	79	78	5.85	5.78	12857	12721
57	"	24.20	75.80	93	92	6.89	6.82	12857	12721
35	Pennsylvania No. 18 (one-half) and Rhode Island No. 1 (one-half)	13.89	86.11	86	85	6.37	6.30	13569	13387
49	Pennsylvania No. 18 (three-fourths) and Miscellaneous No. 9 (one-fourth)	19.30	80.70	79	77	5.85	5.70	13431	13185
50	Pennsylvania No. 18 (one-half) and Miscellaneous No. 9 (one-half)	28.05	71.95	83	81	6.15	6.00	12955	12787
51	"	28.05	71.95	81	80	6.00	5.92	12955	12787
7	Virginia No. 5 B	24.07	75.93	89	85	6.59	6.30	13136	12542
8	"	24.07	75.93	79	75	5.87	5.56	13136	12542

TABLE 16 TESTS OF FUEL IN HOUSE-HEATING BOILER AT ST. LOUIS—(*Continued*)

Test No.	Designation of Fuel	Water pounds		Factor of Evaporation	Equivalent Evaporation per hour from and at 212°F. (pounds)	Horsepower Developed	Equivalent Evaporation per hour from and at 212° F. per sq. ft. of Water Heating Surface (pounds)	Mean Load Carried (sq. ft. of radiating surface)	Percentage of Builders' Rated Capacity Developed
		Fed to Boiler	Evaporated into Dry Steam from and at 212° F.						
		49	**52**	**51**	**53**	**53.1**	**54**	**55**	**56**
45	Arkansas No. 13	4186	4487	1.0720	539	15.6	3.39	1797	57.0
58	Illinois No. 1	3422	3754	1.0970	474	13.7	2.98	1580	50.2
59	"	3809	4159	1.0919	520	15.1	3.27	1733	55.0
48	Illinois No. 7 E	3708	3989	1.0759	499	14.5	3.14	1663	52.8
39	Illinois No. 9 C	3786	4089	1.0800	493	14.3	3.10	1643	52.2
13	Illinois No. 12 BW	3188	3430	1.0758	416	12.1	2.62	1387	44.0
52	Illinois No. 19 E	3625	3914	1.0798	502	14.6	3.16	1673	53.1
53	"	4482	4886	1.0902	592	17.2	3.73	19[illegible]3	62.6
54	"	3325	3599	1.0825	447	13.0	2.81	1490	47.3
55	"	3959	4334	1.0946	554	16.1	3.49	1847	58.7
9	Illinois No. 29 A W	4900	5239	1.0692	665	19.3	4.18	2217	70.4
12	Illinois No 29 B	4134	4423	1.0700	615	17.8	3.87	2050	65.1
33	Illinois No. 31	3960	4407	1.1130	563	16.3	3.54	1877	59.6
34	"	4292	4801	1.1187	594	17.2	3.74	1980	62.9
44	"	4248	4585	1.0794	550	15.9	3.46	1833	58.2
43	Illinois No. 33	3805	4075	1.0710	521	15.1	3.28	1737	55.2
37	Indiana No. 1 B	4915	5399	1.0985	648	18.8	4.08	2160	68.6
36	Indiana No. 5 B	4523	5048	1.1161	600	17.4	3.77	2000	63.5
38	Indiana No. 6 B	3962	4272	1.0782	542	15.7	3.41	1807	57.4
10	Indian Territory No. 2 BW	4866	5198	1 0682	656	19.0	4.13	2187	69.4
11	Indian Territory No. 2 B	5411	5739	1.0606	729	21.1	4.58	2430	77.2
1	Kansas No. 2 B	3433	3686	1.0737	461	13.4	2.90	1537	48.8
40	"	4023	4357	1.0829	528	15.3	3.32	1760	55.9
21	Maryland No. 2	4895	5224	1.0673	653	18.9	4.11	2177	69.1
22	"	4188	4489	1.0719	599	17.4	3.77	1997	63.4
23	"	4260	4581	1.0754	573	16.6	3.60	1910	60.6
20	"	4079	4377	1.0731	556	16.1	3.50	1853	58.8
2	Missouri No. 10	5152	5498	1.0671	718	20.8	4.52	2393	76.0
3	"	3824	4087	1.0688	522	15.1	3.28	1740	55.2
4	"	4036	4356	1.0792	557	16.1	3.50	1857	59.0
5	"	5415	5755	1.0627	708	20.5	4.45	2360	74.9
28	Pennsylvania No. 18	3720	4014	1.0790	502	14.6	3.16	1673	53.1
29	"	4879	5246	1.0752	656	19.0	4.13	2187	69.4
30	"	4404	4722	1.0723	613	17.8	3.86	2043	64.9
31	"	4095	4393	1.0728	549	15.9	3.45	1830	58.1
46	"	4343	4710	1.0845	579	16.8	3.64	1930	61.3
24	"	4209	4520	1.0740	565	16.4	3.55	1883	59.8
25	"	4113	4413	1.0729	552	16.0	3.47	1840	58.4
32	Pennsylvania No. 19	3142	3480	1.1076	529	15.3	3.33	1763	56.0
15	"	3239	3487	1.0765	465	13.5	2.92	1550	49.2
26	Pennsylvania No. 20	4069	4367	1.0733	546	15.8	3.43	1820	57.8
27	"	3829	4126	1.0775	516	15.0	3.25	1720	54.6
41	Pennsylvania No. 20 W	4416	4735	1.0723	606	17.6	3 81	2020	64.2
42	"	2703	2931	1.0844	564	16.3	3.55	1880	59.7
16	Pennsylvania No. 22	3473	3743	1.0776	478	13.9	3.01	1593	50.6
17	"	3531	3816	1.0807	472	13.7	2.97	1573	49.9
18	"	3457	3723	1.0769	465	13.5	2.92	1550	49.2
19	"	3627	3909	1.0777	486	14.1	3.06	1620	51.4
14	"	3844	4132	1.0748	545	15.8	3.43	1817	57.7
47	Pennsylvania No. 15 (one-half) and Rhode Island No. 1 (one-half)	3993	4273	1.0700	519	15.0	3.26	1730	54.9
56	Pennsylvania No. 18 (one-fourth) and Miscellaneous No. 9 (three-fourths)	4173	4555	1.0915	558	16.2	3.51	1860	59.1
57	"	3698	4042	1.0929	577	16.7	3.63	1923	61.0
35	Pennsylvania No. 18 (one-half) and Rhode Island No. 1 (one-half)	3118	3485	1.1177	616	17.9	3.87	2053	65.2
49	Pennsylvania No. 18 (three-fourths) and Miscellaneous No. 9 (one-fourth)	4308	4636	1.0761	563	16.3	3.54	1877	59.6
50	Pennsylvania No. 18 (one-half) and Miscellaneous No. 9 (one-half)	3860	4158	1.0773	531	15.4	3.34	1770	56.2
51	"	3928	4237	1.0787	530	15.4	3.33	1767	56.1
7	Virginia No. 5 B	5353	5678	1.0608	710	20.6	4.47	2367	75.1
8	"	4270	4544	1.0642	583	16.9	3.67	1943	61.6

TABLE 16 TESTS OF FUEL IN HOUSE-HEATING BOILER AT ST. LOUIS—(*Continued*)

Test No.	Designation of Fuel	Economic Results pounds				Efficiency per cent	
		Equivalent Evaporation from and at 212° F. per pound of Fuel		Fuel per hour per 100 square feet of Radiating Surface (mean load carried during test)		Boiler and Furnace (dry fuel basis)	Plant (fuel as fired basis)
		As Fired	Dry	As Fired	Dry		
		57	58	59	60	61	62
45	Arkansas No. 13..................	5.77	6.14	5.18	5.12	45.22	43.14
58	Illinois No. 1......................	4.40	5.32	6.84	5.89	42.19	40.33
59	"	4.76	5.71	6.29	5.48	45.28	43.63
48	Illinois No. 7 E.................	4.13	4.56	7.28	6.80	41.28	39.80
39	Illinois No. 9 C.....	4.69	5.18	6.39	6.02	40.39	38.67
13	Illinois No. 12 BW..............	5.15	5.84	5.84	5.34	43.52	41.69
52	Illinois No. 19 E..................	4.79	5.39	6.28	5.80	41.94	40.22
53	"	5.27	5 91	5.68	5.27	45.99	44.25
54	"	4.44	4.97	6.78	6.24	38.67	37.28
55	"	5.67	6.33	5.30	4.87	49.25	47.61
9	Illinois No. 29 A W...............	6.98	8.08	4.29	3.79	58.64	57.75
12	Illinois No. 29 B...................	6.02	6.59	4.98	4.68	50 66	49.45
33	Illinois No. 31......................	5.42	6.08	5.54	5.00	48 83	47.93
34	"	5.74	6.46	5.20	4.75	51.88	50.76
44	"	4.74	5.21	6.33	5.89	41.94	41.02
43	Illinois No. 33......................	4.19	5.36	7.14	6.50	48.01	41.45
37	Indiana No. 1 B........	4.89	5.21	6.16	5.88	42.25	41.46
36	Indiana No. 5 B....................	5.44	5.82	5.50	5.30	43.33	42.28
38	Indiana No. 6 B....................	5.24	5.70	5.70	5.37	43.84	42.74
10	Indian Territory No. 2 BW.....	7.06	7.58	4.25	4.16	52.79	50.28
11	Indian Territory No. 2 B........	7.79	8.20	3.87	3.79	60.01	58.26
1	Kansas No. 2 B....................	5.53	5.69	5.40	5.27	45.29	45.28
40	"	5.45	5.86	5.51	5.34	47.74	45.99
21	Maryland No. 2....................	8.02	8.54	3.77	3.63	56.13	54.69
22	"	8.02	8.41	3.76	3.55	55.27	54.69
23	"	7.05	7.50	4.24	4.08	49.29	48.08
20	"	8.42	8.72	3.56	3.51	58.18	57.15
2	Missouri No. 10....	4.75	5.58	6.31	5.64	46.50	44.49
3	"	5.31	6.28	5.63	5.00	52.34	49.74
4	"	5.32	6.27	5.66	5.01	52.25	49.83
5	"	5.55	6.41	5.38	4.79	53.42	51.98
28	Pennsylvania No. 18.......	6.92	7.56	4.37	4.01	50.67	50.10
29	"	8.05	8.78	3.75	3.48	58.85	58.28
30	"	9.00	9.52	3.33	3.18	63.15	62.65
31	"	7.99	8.52	3.77	3.61	56.51	55.62
46	"	7 21	7.72	4.14	4.04	52 71	50.90
24	"	8.22	8.58	3.67	3.56	58.78	57.44
25	"	8.02	8.52	3.75	3.59	57.23	55.86
32	Pennsylvania No. 19............	6.43	6.60	4.65	4.60	45.89	45.50
15	"	7.64	7.96	3.94	3.87	54 92	53.81
26	Pennsylvania No. 20............	8.32	9.02	3.63	3.41	61.94	60.88
27	"	7.50	8.12	4.01	3 78	55.76	54.88
41	Pennsylvania No. 20 W.........	7.97	8.21	3.76	3.71	56.35	55.39
42	"	7 56	7.84	3.99	3.94	53.81	52.54
16	Pennsylvania No. 22	6.81	7.20	4.40	4.33	50.14	48.50
17	"	7.10	7.41	4.26	4.13	51.60	50.56
18	"	6.74	7.41	4.45	4.32	51.99	49.03
19	"	7.09	7.76	4.20	4.07	54.45	51.58
14	"	8.40	9.00	3.58	3.52	62.93	59.79
47	Pennsylvania No. 15 (one-half) and Rhode Island No. 1 (one-half)........................	6.55	6.94	4.57	4.57	52.01	49.44
56	Pennsylvania No. 18 (one-fourth) and Miscellaneous No. 9 (three-fourths)..............	7.08	7.52	4.25	4.19	56.48	53.75
57	"	6.20	6.60	4.84	4.79	49.57	47.07
35	Pennsylvania No. 18 (one-half) and Rhode Island No. 1 (one-half)........................	7.13	7.34	4.19	4.14	52.24	51.43
49	Pennsylvania No. 18 (three-fourths) and Miscellaneous No. 9 (one-fourth)............	7.16	7.61	4.21	4.10	54.72	52.44
50	Pennsylvania No. 18 (one-half) and Miscellaneous No. 9 (one-half)........................	6.44	6.98	4.69	4.57	52.03	48.64
51	"	6.51	7.09	4.59	4.53	52.85	49.16
7	Virginia No. 5 B..................	7.98	8.89	3.76	3.59	65.36	61.44
8	"	7.42	8 28	4.07	3.86	60.87	57.13

TABLE 16 TESTS OF FUEL IN HOUSE-HEATING BOILER AT ST. LOUIS—(*Concluded*).

Test No.	Designation of Fuel	Fuel at $1 per 2000 pounds: Cost in cents per 100 square feet of Radiating Surface per hour (mean load carried during test)	Fuel at $1 per 2000 pounds: Cost (in cents) of Evaporating 1000 pounds of Water from and at 212° F.	Thickness of Fire inches	Average Amount of Fuel Fired at each Firing pounds	Average Interval Between Firings hours	Clinkers in Refuse per cent	Black Smoke per cent
		64	65	69	70	71		77
45	Arkansas No. 13	0.2590	8.67	8–16	155	1.66	15	30.3
58	Illinois No. 1	.3420	11.36	8–14	171	1.58	38	25.7
59	"	.3150	10.50	8–16	175	1.60	38	41.2
48	Illinois No. 7 E	.3640	12.10	....	161	1.33	19	40.3
39	Illinois No. 9 C	.3200	10.65	....	145	1.36	28	32.6
13	Illinois No. 12 BW	.2420	9.71	....	74	.92	0	24.1
52	Illinois No. 19 E	.3140	10.44	4–12	163	1.56	0	37.1
53	"	.2840	9.49	8–16	155	1.37	20	30.3
54	"	.3390	11.25	8–16	162	1.61	21	32.5
55	"	.2650	8.82	6–14	153	1.56	0	31.5
9	Illinois No. 29 AW	.2150	7.16	....	62	.66	0	19.2
12	Illinois No. 29 B	.2490	8.31	....	67	.65	26	34.6
33	Illinois No. 31	.2770	9 23	....	163	1.56	13	22.7
34	"	.2600	8.71	....	167	1.61	24	23.7
44	"	.3170	10.55	8–16	161	1.39	46	29.1
43	Illinois No. 33	.3570	11.93	6–18	162	1.30	14	32.8
37	Indiana No. 1 B	.3080	10.22	4–16	158	1.19	48	28.5
36	Indiana No. 5 B	.2750	9.19	4–14	155	1.40	34	32.2
38	Indiana No 6 B	.2850	9.54	8–14	163	1.58	47	32 3
10	Indian Territory No. 2 BW	.2130	7.08	....	74	.79	0	30.4
11	Indian Territory No. 2 B	.1940	6.42	....	67	.71	0	25.2
1	Kansas No. 2 B	.2700	9.04	....	56	.66	44	22.6
40	"	.2760	9.18	6–18	160	1.65	33	26.4
21	Maryland No. 2	.1890	6.24	....	93	1.14	0	14.4
22	"	.1880	6.24	...	140	1.32	0	....
23	"	.2120	7.09	....	163	2.00	0	10.7
20	"	.1780	5.94	....	65	.98	0	1.4
2	Missouri No. 10	.3160	10.52	....	116	.77	29	41.6
3	"	.2820	9.42	....	55	.56	38	51.4
4	"	.2830	9.40	....	55	.52	29	30.6
5	"	.2690	9.01	....	65	.51	30	41.1
28	Pennsylvania No. 18	.2190	7.23	....	145	2.00	0	12.7
29	"	.1880	6.21	....	163	2.00	0	14.2
30	"	.1670	5.56	....	131	1.92	0	25.5
31	"	.1890	6.26	4–12	138	2.00	0	36.8
46	"	.2070	6.94	....	163	2.03	20	26.7
24	"	.1840	6.08	....	138	2.00	0	7.2
25	"	.1880	6.24	....	138	2.00	0	9.2
32	Pennsylvania No. 19	.2330	7.78	....	135	1.64	0	45.7
15	"	.1970	6.54	....	41	.68	0	14.2
26	Pennsylvania No. 20	.1820	6.01	....	131	2.00	0	16.6
27	"	.2010	6.67	....	138	2.00	0	17.7
41	Pennsylvania No. 20 W	.1880	6.27	4–16	148	1.96	0	29.7
42	"	.2000	6.61	6–18	129	1.73	0	....
16	Pennsylvania No. 22	.2200	7.34	....	61	.87	0	25.1
17	"	.2130	7.04	....	60	.89	0	26.7
18	"	.2230	7.42	....	69	1.00	0	23.3
19	"	.2100	7.05	....	138	2.01	0	22.9
14	"	.1790	5.96	....	62	.95	0	16.1
47	Pennsylvania No. 15 (one-half) and Rhode Island No. 1 (one-half)	.2290	7.64	4–18	163	2.06	24	29.9
56	Pennsylvania No. 18 (one-fourth) and Miscellaneous No. 9 (three-fourths)	.2130	7.06	8–18	161	2.04	24	32.2
57	Pennsylvania No. 18 (one half) and Rhode Island No. 1 (one half)	.2420	8.06	8–16	163	1.75	25	31.4
35	"	.2100	7.01	4–12	162	1.88	0	19.3
49	Pennsylvania No. 18 (three fourths) and Miscellaneous No. 9 (one fourth)	.2110	6.98	....	162	2.06	16	....
50	Pennsylvania No. 18 (one-half) and Miscellaneous No. 9 (one-half)	.2350	7.77	8–16	162	1.96	0	28.9
51	"	.2300	7.68	10–18	163	2.00	0	32.6
7	Virginia No. 5 B	.1880	6.27	....	65	.73	0	16.7
8	"	.2010	6.74	....	123	1.56	0	39.5

TABLE 17

Average Percentage of CO_2, O_2, and CO from 52 Tests Made on Fuel in House-heating Boiler at St. Louis

Test No.	CO_2	O_2	CO	Test No.	CO_2	O_2	CO
7	10.1	6.35	0.40	34	7.2	10.9	0,1
8	10.9	5.4	1.02	35	7.8	9.80	.10
9	10.22	7.56	.7	36	7.9	8.3	.96
10	9.74	8.44	.34	37	12.1	4.3	.75
11	7.57	10.0	.68	38	9.3	6.8	.55
12	9.26	8.30	.44	39	8.75	5.45	1.0
13	6.96	11.35	.20	40	8.2	8.86	.53
14	7.0	10.68	.52	41	6.7	10.8	.20
15	5.8	11.30	.18	42	7.1	9.8	.25
16	6.8	11.3	.56	43	6.8	11.4	,4
17	6.8	10.26	.43	44	7.6	9.4	.4
18	7.2	9.85	.65	45	13.3	4.3	.6
19	8.0	8.77	.84	46	10.3	6.75	.65
20	7.13	9.83	.53	47	9.2	9.25	.15
21	8.6	7.25	.51	48	8.3	9.8	.6
22	8.0	6.58	1.62	49	8.1	9.80	.60
23	7.5	7.40	1.28	50	8.6	9.3	.15
24	6.8	11.84	.24	51	9.4	9.0	.60
25	7.0	11.60	.11	52	8.75	7.65	1.50
26	7.6	10.35	.28	53	9.8	6.65	1.0
27	5.8	12.81	.05	54	9.7	6.5	.6
28	7.5	10.75	.46	55	12.5	4.0	.75
29	7.4	10.76	.34	56	9.8	7.10	.40
30	7.4	10.63	.13	57	9.9	7.90	.25
31	6.5	10.40	.30	58	9.3	8.1	.45
32	7.0	10.35	.15	59	9.7	7.4	1.2

APPENDIX C

TABLE 18

Tests of Fuel in House-heating Boilers Made at the Engineering Experiment Station University of Illinois*

Tests on Briquets

Test No.	Boiler	Designation of Fuel	Shape of Briquets	Date	Duration of Test hours	Average Pressure: Steam gage: Boiler	Average Pressure: Steam gage: Receiver	Average Pressure: Draft (in. of water): Flue	Average Pressure: Draft (in. of water): Over Fire	Average Temperature (°F.): External Air	Average Temperature (°F.): Boiler Room	Average Temperature (°F.): Feed Water in Weigh Tank
				1907	1	10	11	12	13	14	15	16
136	D1	Illinois No. 7 E......	Round..	June 19.	8.62	4.25	1.87	0.15	0.10	..	..	148 9
137	D2	"	" ..	"	7.38	4.98	1.58	.16	.06	..	.	158.0
152	D1	Illinois No. 9 C.... ..	" ..	June 28.	7.78	6.39	2.02	.15	.12	74	79	164.5
153	D2	"	" ..	"	8.02	5.04	1.71	.15	.06	74	79	168.3
154	D1	Illinois N W....	" ..	June 29.	7.97	7.04	2.06	.15	.12	82	83	159.9
155	D2	"	" ..	"	7.50	3.60	1.32	.13	.03	82	83	161.6
142	D1	Illinois No. 31........	" .	June 22.	7.35	6.69	2.05	.15	.11	..	..	151.3
143	D2	"	" ..	"	6.85	5.22	1.67	.15	.05	..	..	153.7
144	D1	"	Square..	June 24.	7.93	5.61	1.94	.17	.10	..	..	150.8
145	D2	"	" ..	"	7.52	6.02	1.70	.22	.04	..	..	144.5
158	D1	Illinois No. 33........	Round..	July 2.	7.97	6.78	2.05	.15	.12	75	81	165.1
159	D2	"	" ..	"	8.15	5.34	1.71	.18	.05	75	81	166.0
140	D1	Indiana No. 1 B......	" ..	June 21.	7.97	6.12	2.08	.15	.12	..	..	152.3
141	D2	"	" ..	"	7.47	5.30	1.68	.18	.04	..	..	157.0
146	D1	Indiana No. 6 B......	" ..	June 25.	8.05	6.32	1.97	.15	.11	78	82	169.1
147	D2	"	" ..	"	8.00	3.76	1.46	.19	.02	78	82	173.4
148	D1	"	Square..	June 26.	8.08	6.59	2.07	.17	.13	77	83	155.8
149	D2	"	" ..	"	8.25	5.44	1.74	.17	.05	77	83	156.6
138	D1	Missouri No. 10......	Round..	June 20.	7.95	5.68	1.97	.14	.10	..	..	163.1
139	D2	"	" ..	"	7.67	4.44	1.86	.20	.05	..	..	162.7
156	D1	Pennsylvania No. 20 W.	" ..	July 1.	9.17	6.11	2.00	.14	.12	83	88	167.2
157	D2	"	" ..	"	8.02	5.40	1.60	.14	.07	83	88	169.7
150	D1	Pennsylvania No. 22.	Square..	June 27.	8.13	5.72	2.02	.18	.14	74	79	157.5
151	D2	"	" ..	"	8.45	6.09	1.86	.15	.06	74	79	165.4

*See "21. Data and Results," p. 63.

TABLE 18

Tests of Fuel in House-heating Boilers Made at the Engineering Experiment Station, University of Illinois—(*Continued*)

Tests on Briquets

Test No.	Boiler	Designation of Fuel	Fuel as Fired (pounds)				Dry Fuel (pounds)			Total Ash and Refuse from Ash Pit (pounds)	Residual Fuel Removed (pounds)
			Wood	Briquets	Briquets plus Wood	Corrected for residual Fuel	Total Fired	Corrected for Residual Fuel	Actually Consumed (Corrected for Carbon in Ash)		
			20	21	21.1	21.2	23	23.1	23.2	24	25
136	D1	Illinois No. 7 E.......	6.0	372	374.4	340.5	347.9	316.4	307.4	34.0	82.5
137	D2	"	6.2	335	337.5	318.9	313 6	296.3	272.8	76.0	34.0
152	D1	Illinois No. 9 C.......	10.0	275	279.0	266 2	259.8	247.8	245.2	26.0	27.0
153	D2	"	10.0	375	379 0	363.0	352.9	338.0	325.8	51.0	23.5
154	D1	Illinois No. 30 W......	10.0	255	259.0	251.1	242.6	235.2	233.9	13.0	14,2
155	D2	"	10.0	300	304.0	280.5	284.7	262.7	256.9	23.0	27.7
142	D1	Illinois No. 31.........	6.0	265	267.4	253,9	241.9	229.7	224.0	27.0	24.0
143	D2	"	10.0	275	279.0	269.3	252.4	243 6	232.6	45.0	14.0
144	D1	"	7.5	275	278,0	267.8	254.5	245.2	236.1	35.5	16.0
145	D2	"	7 2	300	302.9	288.9	277.3	264 4	249,7	42.5	20.5
158	D1	Illinois No. 33.........	10,0	260	264.0	254.6	247.5	238.6	235.8	24.0	19.0
159	D2	"	10.5	340	344.2	326.8	322.7	306.3	301.4	34.5	26.5
140	D1	Indiana No. 1 B.......	10.0	275	279.0	268.7	260.0	250.4	240.6	32.5	16.0
141	D2	"	10.0	300	304.0	291.8	283.3	271.9	261.4	43.0	15.5
146	D1	Indiana No. 6 B.......	10.0	265	269.0	261.4	255.3	248.1	244.2	23.0	17,5
147	D2	"	10.0	340	344.0	318.6	326.5	302.4	297.2	33.5	33.0
148	D1	"	10.0	265	269.0	253,2	255.8	240 8	238.8	21.0	31.5
149	D2	"	10.0	340	344.0	326.3	327.1	310.3	303,5	38.5	26.5
138	D1	Missouri No 10,.....	6.0	300	302 4	282.5	282.6	264 0	247.5	57.0	27.0
139	D2	"	6.0	375	377.4	360.2	352.6	336.5	322.7	62.5	32.0
156	D1	Pennsylvania No.20W	10 0	225	229.0	214.6	221 8	207 8	202.7	17.2	16.0
157	D2	" "	11.0	225	229.4	217.4	225.2	210.6	201 9	22 0	14.7
150	D1	Pennsylvania No. 22..	10.0	225	229.0	209.2	220.7	201.6	196.7	20.0	24.0
151	D2	" "	10.0	226	280.0	252.5	269.9	243.4	236.0	25.0	38.0

TABLE 18

Tests of Fuel in House-heating Boilers made at Engineering Experiment Station University of Illinois—(*Continued*)

Tests on Briquets

Test No.	Boiler	Designation of Fuel	Proximate Analysis of Fuel as Fired per cent				Ash in Ultimate Analysis of Dry Fuel (per cent)	Residual Fuel per cent	
			Fixed Carbon	Volatile Matter	Moisture	Ash		Carbon	Earthy Matter
			26	27	28	29	35	37	38
136	D1	Illinois No. 7 E	....	....	7.07	....	27.43	26.50	73.50
137	D2	"	....	....	7.07	....	27.43	35.34	64.66
152	D1	Illinois No. 9 C	....	....	6.89	....	14.69	35.87	64.13
153	D2	"	....	....	6.89	....	14.69	51.44	48.56
154	D1	Illinois No. 30 W	....	....	6.34	....	8.35	46.47	53.53
155	D2	"	....	....	6.34	....	8.35	71.34	28.66
142	D1	Illinois No. 31	....	....	9.53	....	16.81	40.71	59.29
143	D2	"	....	....	9.53	....	16.81	50.39	49.61
144	D1	"	....	....	8.46	....	16.76	46.16	53.84
145	D2	"	....	....	8.46	....	16.76	49.72	50.28
158	D1	Illinois No. 33	....	....	6.26	....	13.67	40.06	59.94
159	D2	"	....	....	6.26	....	13.67	53.09	46.91
140	D1	Indiana No. 1 B	....	....	6.80	....	14.11	50.81	49.19
141	D2	"	....	....	6.80	....	14.11	62.24	37.76
146	D1	Indiana No. 6 B	....	....	5.08	....	12.27	35.80	64.20
147	D2	"	....	....	5.08	....	12.27	63.04	36.96
148	D1	"	....	....	4.91	....	13.51	40.29	59.71
149	D2	"	....	....	4.91	....	13.51	53.58	46.42
138	D1	Missouri No. 10	....	....	6.56	....	21.57	51.85	48.15
139	D2	"	....	....	6.56	....	21.57	37.98	62.02
156	D1	Pennsylvania No. 20 W	....	....	3.16	....	7.98	85.21	14.79
157	D2	"	....	....	3.16	....	7.98	76.78	23.22
150	D1	Pennsylvania No. 22	....	....	3.61	....	9.68	74.34	25.66
151	D2	"	....	....	3.61	....	9.68	65.23	34.77

TABLE 18

TESTS OF FUEL IN HOUSE-HEATING BOILERS MADE AT THE ENGINEERING EXPERIMENT STATION UNIVERSITY OF ILLINOIS—(*Continued*)

Tests on Briquets

Test No.	Boiler	Designation of Fuel	Ash (per cent)		Dry Fuel per hour (pounds)		British thermal units per pound of Fuel		Moisture in Steam (per cent)
			Carbon	Earthy Matter	Total	Per square foot of Grate Surface	Dry	As Fired	
			40	41	43	44	45	46	47
136	D1	Illinois No. 7 E	18.30	81.70	36.72	8.58	10142	9425	1.02
137	D2	"	21.47	78.53	40.13	6.69	10142	9425	.61
152	D1	Illinois No. 9 C	8.23	91.77	31.84	7.43	11845	11029	.99
153	D2	"	19 44	80.56	42.16	7.03	11845	11029	.90
154	D1	Illinois No. 30 W	9.32	90.68	29.52	6.90	13134	12301	.82
155	D2	"	22.77	77.23	35.03	5.84	13134	12301	1.11
142	D1	Illinois No. 31	17.01	82.99	31.25	7.30	11685	10571	.83
143	D2	"	19.50	80.50	35.56	5.93	11685	10571	.66
144	D1	"	20.30	79.70	30.90	7.22	11574	10595	1.09
145	D2	"	27.41	72.59	35.17	5.86	11574	10595	.72
158	D1	Illinois No. 33	10.26	89.74	29.95	7.00	12573	11786	.95
159	D2	"	12.38	87.62	37.58	6.26	12573	11786	.89
140	D1	Indiana No. 1 B	25.57	74.43	31.43	7.34	12379	11537	.85
141	D2	"	20.85	79.15	36.42	6.07	12379	11537	.69
146	D1	Indiana No. 6 B	14.58	85.42	30.82	7.20	12617	11976	.90
147	D2	"	13.47	86.53	37.81	6.30	12617	11976	.93
148	D1	"	7.87	12.13	29.78	6.96	12319	11714	.76
149	D2	"	14.94	85.06	37 61	6.27	12319	11714	.81
138	D1	Missouri No. 10	21.87	78.13	33.21	7.76	11012	10290	.93
139	D2	"	16.64	83.36	43.89	7.32	11012	10290	.65
156	D1	Pennsylvania No. 20 W	28.87	71.13	22.67	5.30	14262	13811	.98
157	D2	"	38.61	61.39	26.26	4.38	14262	13811	.78
150	D1	Pennsylvania No. 22	23.17	76.83	24.79	5.79	13646	13153	1.08
151	D2	"	27.70	72.30	28.80	4.80	13646	13153	.80

TABLE 18

Tests of Fuel in House-heating Boilers Made at the Engineering Experiment Station, University of Illinois—(*Continued*)

Tests on Briquets

Test No.	Boiler	Designation of Fuel	Factor for Correction, Quality of Steam	Water pounds: Fed to Boiler	Water pounds: Corrected for Quality of Steam	Water pounds: Evaporated into Dry Steam from and at 212° F.	Factor of Evaporation	Water per hour pounds: Equivalent Evaporation from and at 212° F.	Water per hour pounds: Equivalent Evaporation from and at 212° F. per square foot of Water-heating Surface	Horse-power Developed
			48	49	50	52	51	53	54	
136	D1	Illinois No. 7 E	0.9905	1292	1280	1366	1.0677	158.5	3.63	4.59
137	D2	"	.9943	1386	1377	1457	1.0580	197.3	2.69	5.72
152	D1	Illinois No. 9 C	.9907	1215	1204	1266	1.0517	162.7	3.72	4.72
153	D2	"	.9914	1589	1575	1650	1.0477	205.8	2.80	5.97
154	D1	Illinois No. 30 W	.9923	1302	1292	1365	1.0566	171.3	3.92	4.97
155	D2	"	.9895	1234	1221	1287	1.0542	171.6	2.34	4.97
142	D1	Illinois No. 31	.9923	1147	1138	1212	1.0655	165.0	3.78	4.78
143	D2	"	.9938	1346	1337	1421	1.0626	207.5	2.83	6.01
144	D1	"	.9900	1228	1216	1296	1.0660	163.5	3.74	4.74
145	D2	"	.9933	1457	1447	1552	1.0722	206.7	2.82	5.99
158	D1	Illinois No. 33	.9910	1270	1259	1323	1.0512	166.0	3.80	4.81
159	D2	"	.9916	1515	1502	1577	1.0497	193.5	2.64	5.61
140	D1	Indiana No. 1 B	.9920	1216	1206	1285	1.0650	161.3	3.69	4.68
141	D2	"	.9935	1281	1273	1350	1.0592	180.7	2.47	5.24
146	D1	Indiana No. 6 B	.9914	1270	1259	1320	1.0469	164.0	3.75	4.76
147	D2	"	.9911	1420	1407	1466	1.0420	183.3	2.50	5.31
148	D1	"	.9929	1299	1289	1368	1.0609	169.2	3.87	4.91
149	D2	"	.9923	1669	1655	1754	1.0598	212.5	2.90	6.16
138	D1	Missouri No. 10	.9912	1243	1232	1297	1.0532	163.2	3.74	4.73
139	D2	"	.9939	1557	1546	1630	1.0534	212.5	2.90	6.16
156	D1	Pennsylvania No. 20 W	.9907	1377	1364	1431	1.0489	156.1	3.57	4.53
157	D2	"	.9926	1555	1543	1614	1.0460	201.3	2.74	5.84
150	D1	Pennsylvania No. 22	.9899	1264	1251	1325	1.0590	163.0	3.73	4.73
151	D2	"	.9924	1689	1676	1761	1.0506	208.4	2.84	6.04

TABLE 18

Tests of Fuel in House-heating Boilers Made at the Engineering Experiment Station University of Illinois—(*Continued*)

Tests on Briquets

Test No.	Boiler	Designation of Fuel	Mean Load Carried		Percentage of Builder's Rated Capacity Developed (per cent)	Economic Results (pounds)			
						Equivalent Evaporation from and at 212° F. per pound of Fuel		Fuel per hour per 100 square feet of radiatting Surface (mean load carried during test)	
			Square Feet Radiating Surface	Square Feet of Radiating Surface plus Radiating Surface of Boiler		Fuel as Fired	Dry Fuel Consumed	As Fired	Dry
			55	55.1	56	57	58	59	60
136	D1	Illinois No. 7 E	528	566	66.0	4.01	4.44	7.48	6.95
137	D2	''	658	761	61.2	4.57	5.34	6.57	6.10
152	D1	Illinois No. 9 C	542	580	67.8	4.76	5.16	6.31	5.87
153	D2	''	686	789	63.8	4.55	5.06	6.60	6.15
154	D1	Illinois No. 30 W	571	609	71.4	5.44	5.84	5.52	5.17
155	D2	''	572	675	53.2	4.59	5.01	6.54	6.12
142	D1	Illinois No. 31	550	588	68.8	4.77	5.41	6.28	5.68
143	D2	''	692	795	64.3	5.28	6.11	5.68	5,14
144	D1	''	545	583	68.2	4.84	5.49	6.19	5.67
145	D2	''	689	792	64.1	5.37	6.22	5.58	5.10
158	D1	Illinois No. 33	553	591	69.2	5.20	5.61	5.77	5.41
159	D2	''	645	748	60.0	4.83	5.23	6.22	5.83
140	D1	Indiana No. 1 B	538	576	67.2	4.78	5.34	6.27	5.85
141	D2	''	602	706	56.0	4.63	5.16	6.49	6.05
146	D1	Indiana No. 6 B	547	585	68.3	5,05	5.41	5.94	5.64
147	D2	''	611	714	56.8	4.60	4.93	6.52	6.19
148	D1	''	564	602	70.5	5.40	5.73	5.55	5.28
149	D2	''	708	812	65.8	5.38	5.78	5.58	5.31
138	D1	Missouri No. 10	544	582	68.0	4.59	5.24	6.53	6.10
139	D2	''	708	812	65.9	4.53	5.05	6.63	6.20
156	D1	Pennsylvania No. 20 W	520	558	65.0	6.67	7.06	4.50	4.36
157	D2	''	671	774	62.4	7.42	7.99	4.04	3.91
150	D1	Pennsylvania No. 22	543	581	67.9	6.33	6.74	4.73	4.56
151	D2	''	695	798	64.6	6.97	7.46	4.30	4.15

TABLE 18

TESTS OF FUEL IN HOUSE-HEATING BOILERS MADE AT THE ENGINEERING EXPERIMENT STATION, UNIVERSITY OF ILLINOIS—(*Concluded*)

Tests on Briquets

Test No.	Boiler	Designation of Fuel	Efficiency per cent: Boiler and Furnace	Efficiency per cent: Plant	Cost (in cents) per 100 sq. ft. of Radiating Surface per hour (mean load carried during test) *a*	Cost (in cents) of Evaporating 1,000 lb. of Water from and at 212° F. *a*	Average Amount of Fuel Fired at each Firing (pounds)	Average Interval hours: Between Firings	Average Interval hours: Between Times of Shaking and Raking	Maximum Interval of Maintaining 2 lb. or more Steam Pressure without Attention (hours)
			61	62	64	65	70	71	72	73
136	D1	Illinois No. 7 E	42.28	41.09	0.374	12.47	75	1.53	1.02	2.00
137	D2	"	50.85	46.83	.374	10.94	45	1.04	.76	1.77
152	D1	Illinois No. 9 C	42.07	41.69	.328	10.50	75	2.13	2.13	2.22
153	D2	"	41.26	39.84	.316	10.99	75	1.76	1.77	2.22
154	D1	Illinois No. 30 W	42.94	42.71	.330	9.19	75	2.40	2.40	2.55
155	D2	"	36.84	36.04	.276	10.89	75	1.74	1.74	2.37
142	D1	Illinois No. 31	44.72	43.58	.327	10.48	75	2.31	2.31	2.38
143	D2	"	50.50	48.24	.314	9.47	75	2.13	2.13	2.73
144	D1	"	45.81	44.12	.284	10.33	75	2.52	2.52	2.60
145	D2	"	51.90	48.95	.310	9.31	75	2.01	2.01	2.25
158	D1	Illinois No. 33	43.09	42.61	.279	9.62	75	2.61	2.61	2.83
159	D2	"	40.17	39.58	.289	10.35	75	1.91	1.91	2.62
140	D1	Indiana No. 1 B	41.66	40.02	.311	10.46	75	2.21	2.21	2.22
141	D2	"	40.26	38.76	.314	10.80	75	1.94	1.94	2.05
146	D1	Indiana No. 6 B	41.41	40.73	.325	9.90	75	2.54	2.54	3.03
147	D2	"	37.74	37.10	.297	10.87	75	1.89	1.89	2.48
148	D1	"	44.92	44.52	.326	9.26	75	2.73	2.81	3.62
149	D2	"	45.31	44.36	.278	9.29	75	2.14	2.14	1.83
138	D1	Missouri No. 10	45.96	43.08	.279	10.89	75	1.91	1.91	2.00
139	D2	"	44.29	42.52	.327	11.04	75	1.42	1.46	1.67
156	D1	Pennsylvania No. 20 W	47.81	46.64	.332	7.50	75	3.25	3.25	3.60
157	D1	"	54.11	51.89	.225	6.74	75	3.12	3.13	3.35
150	D1	Pennsylvania No. 22	47.70	46.48	.202	7.90	75	3.44	3.44	3.68
151	D2	"	52.80	51.18	.215	7.17	75	2.51	2.52	2.17

a Based on fuel as $1 per 2000 lb.

Publications of The Engineering Experiment Station

Bulletin No. 1. Tests of Reinforced Concrete Beams, by Arthur N. Talbot. 1904. (*Out of print*).

Circular No. 1. High-Speed Tool Steels, by L. P. Breckenridge. 1905. (*Out of print*)

Bulletin No. 2. Tests of High-Speed Tool Steels on Cast Iron, by L. P. Breckenridge and Henry B. Dirks. 1905. (*Out of print*).

Circular No. 2. Drainage of Earth Roads, by Ira O. Baker. 1906. (*Out of print*).

Circular No, 3. Fuel Tests with Illinois Coal. (Compiled from tests made by the Technologic Branch of the U. S. G. S., at the St. Louis, Mo., Fuel Testing Plant, 1904-1907, by L. P. Breckenridge and Paul Diserens. 1909.

Bulletin No. 3. The Engineering Experiment Station of the University of Illinois, by L. P. Breckenridge. 1906. (*Out of print*).

Bulletin No. 4. Tests of Reinforced Concrete Beams, Series of 1905, by Arthur N. Talbot. 1906.

Bulletin No. 5. Resistance of Tubes to Collapse, by Albert P. Carman. 1906. (*Out of print*).

Bulletin No. 6. Holding Power of Railroad Spikes, by Roy I. Webber. 1906. (*Out of print*).

Bulletin No. 7. Fuel Tests with Illinois Coals, by L. P. Breckenridge, S. W. Parr and Henry B. Dirks. 1906. (*Out of print*).

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